The Economics of
Monitoring and Enforcement

Analyses of Trilateral Settings

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geboren in Eckernförde.

Für Cathrin und Frida.

Ihr habt großartig durchgehalten.

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1 Introduction

1.1 The economics of monitoring and enforcement

All kinds of human societies feature certain rules that aim to coordinate social interactions and to guide and control human and organizational behavior. The nature of these rules reach from unwritten and sometimes even unuttered implicit social norms (like knocking on a door before entering a room) and mostly self-enforcing legal prescriptions (e.g. the prohibition to smoke at gas stations) to criminal law that prescribes small fines for some offences but also dictates severe sanctions for a number of felonies.

This thesis deals with legal regulations and laws instead of informal norms. For laws and regulations to be effective it must be ensured that at least a certain minimum fraction of those adressed by them comply. In many circumstances, however, actors can benefit from violating. Such benefits can take various forms, e.g. saving time when speeding on the highway, making profits from selling illegal drugs or saving the costs to install pollution abatement equipment. The incentives to violate raise the question what mechanisms society can implement to assure full or at least partial compliance. At a first glance, law enforcement appears to be a topic covered primarily by legal scholars. However, economists have made and are still making considerable contributions when laws are designed and help to answer how they can be enforced efficiently.

Early economic reasoning applied to the subject of monitoring and enforcement dates back to the eighteenth century (Montesquieu 1748, Beccaria 1764, Bentham 1789). Nevertheless, it was Gary Becker's (1968) seminal theory of 'Crime and Punishment' that opened the door for modern economists to contribute to answer questions about law enforcement. The theory is based on the

process \ type of agent	**public**	**private**	
		harmed	not harmed
monitoring	inspections, remote surveillance	victim reporting neighborhood watch	3rd party reporting
enforcement	administrative fines, criminal sanctions	claims on tort law, retaliation	citizen suits, bounty hunting

Figure 1.1: Examples of Monitoring and Enforcement Activities.

observation that a rational, risk-neutral actor commits an offence if and only if the benefit from violating a law exceeds the expected penalty for doing so. The latter is the product of, first, the probability of detection and subsequent punishment and, second, the penalty imposed in case of a conviction. Therefore, the expected penalty is jointly determined by two processes, namely monitoring and enforcement. The monitoring process focusses on informational issues and covers all those actions that contribute to identifying whether an offence was committed and, if so, who the perpetrator is. Enforcement, instead, subsumes all those sanctions that are imposed on an identified violator. In principle, monitoring activities as well as enforcement actions can be undertaken by a public agency or by private parties. Private agents can be differentiated according to whether they are harmed by a violation or whether they are unaffected third parties (see also figure 1.1 which includes some examples). The incentives to participate in monitoring and enforcement typically differ substantially in both situations.

Given that operating a proper monitoring system requires significant resources, e.g. the police, whereas imposing penalties is often less expensive[1], Becker derives the maximum punishment principle. This says that to obtain a certain level of deterrence, i.e. a certain expected punishment, it is optimal to raise the penalty up to its maximum and set the probability of punishment as small as possible as long as it ensures the desired level of deterrence.[2] A similar conclusion is that it is often optimal to bear a positive level of crime: Full compliance requires that the

[1]This certainly holds for monetary fines that are mere transfers except some (often negligible) transaction costs. Whether other types of punishment like imprisonment, incapacitation or even the death penalty are less expensive is an empirical question.

[2]Garoupa (1997) reviews some of the arguments against optimality of maximal sanctions.

expected penalty exceeds the highest benefit any actor can obtain. Achieving this highest level of deterrence might demand additional spendings on monitoring and enforcement which exceed the additional social gains, e.g. the harm prevented, from deterring the actors with the highest benefits.

The tremendous literature following Becker modified, extended and also questioned the theory in several ways by taking different important features into account. Among the most notable are the question whether more harmful acts should be punished more severely (Stigler 1970, Mookherjee and Png 1992, 1994, Wilde 1992, Shavell 1992, Friedman and Sjostrom 1993) and similar how to treat attempts (Shavell 1990); the incorporation of errors in legal proceedings (Harris 1970, Ehrlich 1982, Png 1986) and - related - of fairness concerns (Polinsky and Shavell 2000a); the consideration of dynamic aspects or how to deal with repeat offenders (Landsberger and Meilijson 1982, Greenberg 1984, Davis 1988, Harrington 1988, Polinsky and Rubinfeld 1991); and the analysis of nonmonetary sanctions (Block and Lind 1975, Polinsky and Shavell 1984, Shavell 1985, 1987a, 1987b, Chu and Jiang 1993).[3]

Many of these extensions, however, remain within the traditional *bilateral* setting. This considers, on the one hand, one or more (potential) perpetrators. On the other hand, most models assume a single public agency that is responsible for both monitoring activities and enforcement actions. However, many situations are characterized by a *trilateral* setting. Trilateral settings acknowledge that in many monitoring and enforcement situations at least one third actor is involved. Often such an additional actor can influence the standard monitoring and enforcement process. According to the above differentiation (see again figure 1.1) such a third actor can either be a public authority or a private party. On behalf of public authorities a third type of actor is formed if, for instance, two distinct agencies are responsible for, first, monitoring and, second, enforcement.[4] Other situations arise if two public agencies both carry out monitoring or enforcement activities. One example is the distinction between public prosecutors (also contributing to monitoring) and courts both being involved in enforcement.

[3]See also Polinsky and Shavell (2000b) for an overview of aspects of public enforcement and Cohen (1999) and Heyes (2000) for surveys with a special focus on enforcement of environmental regulations.

[4]Part III analyzes such a situation.

Private actors can carry out monitoring and enforcement actions as well. At the monitoring stage victims can but need not share their information with public authorities (e.g. Garoupa 2001).[5] A similar setting considers whistleblowers (e.g. Miceli and Near 1992, Apesteguia et al. 2007), i.e. people not directly harmed by violations but possessing insider information who are willing to report wrongful conducts. Neighborhood watchprograms are local organizations undertaking monitoring activities to prevent crimes in the vicinity of their homes (e.g. Rosenbaum 1987, Garofalo and McLeod 1989, Skogan 1988, 1989). At the enforcement stage harmed private parties can, for instance, claim on tort law (e.g. Epstein 1973, Rizzo 1980, Shavell 1980). Not directly harmed private parties can participate in enforcement if, for instance, they are authorized to prosecute and arrest violators in exchange for a reward (e.g. Becker and Stigler 1974, Landes and Posner 1975, Polinsky 1980, Friedman 1984).

For various reasons it appears appealing to additionally rely on third actors in monitoring and enforcement. Delegating monitoring and enforcement to two distinct public agencies, for instance, can help to prevent agency capture or lead to specialization benefits.[6] Another obvious example is the potential to save monitoring expenditures if private parties report their - often superior - knowledge about misconducts to public enforcement authorities. Nevertheless, optimally integrating third parties into the process of monitoring and enforcement is often not a straightforward exercise. Public authorities can be bounded by legal restrictions or can pursue own interest. On behalf of private parties it is important to acknowledge that their incentives are rarely aligned with social interest. Thus, given the significant resources required for an effective monitoring and enforcement system it is important to have a sound economic theory that helps to understand *whether* and, if 'yes', *how*, integrating third actors can help to either reduce the costs of or to make monitoring and enforcement more effective. Therefore, the purpose of this thesis is to extend the economic theory of monitoring and enforcement within different trilateral settings.

[5]See also Hylton (1996) who analyzes optimal law enforcement when potential victimes can take precautionary effort.

[6]See for example Hiriart et al. (2010).

1.2 Research questions, methodology, and main findings

This thesis analyzes three different trilateral monitoring and enforcement situations. Parts I and II consider *private monitoring* - a topic that despite its practical importance has attracted only few attention by economists. Part I analyzes reporting by agents that are not harmed by an offence but who are willing to report their observations to public authorities. The analysis in part II considers a special monitoring technology employed by harmed third parties. Part III focusses soley on *public* monitoring and enforcement. The analysis considers two public authorities where one is supposed to add more strength to the *enforcement* stage.

1.2.1 Citizen reporting

Citizens reporting observations of misconducts is an important feature in modern monitoring and enforcement. Violations can be differentiated according to the primary information source for public authorities becoming aware of crimes. Typical cases where public monitoring is the most important source are drunken driving and drug selling. For many violations, however, reporting by private parties is essential. Fields of crime where public agencies naturally and almost exclusively rely on citizen reporting include burglary, fraud, and rape. Offences where public monitoring as well as citizen reporting are significant are violations of product safety regulations, illegal waste disposals, and cartel arrangements. In the U.S., for example, reporting is responsible for 40 percent of crimes known to the police (U.S. DoJ 2003). Such figures raise the question how third party reporting - a potentially low cost information source - can be harnessed more widely for providing deterrence. Part I adresses this question with a special focus on the design of legal rules.

For this purpose part I considers a harmful act but one that does not directly harm others. Unaffected agents, say citizens recognizing only partial compliance with product safety measures, are willing to incur the costs of reporting their (exclusive) information to a public authority, if they provide a 'valuable' input in doing so.[7] The research question is how legal rules should be designed to encourage citizen reporting. Stated differently, part I asks how the presence of citizens, i.e. a modification at the monitoring stage, motivated to share their potentially valuable information, in turn, affects decisions at the stage of defining certain acts to be illegal. To answer this question part I develops a game theoretic model that features three types of players: potential perpetrators, unaffected citizens, and a regulator. The game is characterized by two asymmetric information structures. First, the regulator knows a perpetrator's benefit from committing the act under consideration but citizens do not. Second, citizens observe whether an act was committed but the regulator would have to undertake costly inspections to obtain that information. The main contribution of the model is that it uncovers a potential additional benefit of uniform regulations, i.e. regulations that ban an activity for anyone independent of whether individual private benefits are greater or smaller than social harm. Contrary to tailored standards that account for private benefits a uniform regulation renders citizens' informational shortcomings irrelevant for the reporting decision. Moreover, it provides a novel argument why it can be optimal to bear a positive level of misconducts. Whether it is desirable to impose a uniform ban depends, among other things, on the distribution and levels of private benefits and on the different cost parameters.

1.2.2 Citizen monitoring

The analysis in part I assumes that citizens perfectly observe previous actions. In many situations, however, it is only possible to receive imperfect signals about other agents' behavior. Part II analyzes some of the consequences of improving such a signal's accuracy. The motivating examples are private initiatives like 'water keepers' and 'bucket brigades'. Both are non-governmental organizations whose aim is to contribute to increased environmental quality. The former focus on water quality whereas the latter focus on air quality. Among other activities, such initiatives frequently take samples of the medium of interest and undertake rudimentary analyses to determine pollution intensities. In case of a significant

[7]Part I discusses in detail potential motivations of unaffected citizens to report their observations and thus when they consider their contribution to be 'valuable'.

finding they inform public authorities. Such private initiatives are a still small but growing phenomenon. Bucket brigades by now spread all over the world[8] and the EPA's National Directory of Volunteer Monitoring Programs currently lists roughly 900 organizations in the U.S. that monitor and assess water quality.[9] The imperfection of monitoring devices employed by such initiatives raises the question whether it is beneficial to improve the accuracy of those techniques.

The analysis in part II asks how the use of a better sampling technology - characterized by fewer false negative results - affects public monitoring and enforcement. Although similar in nature to the model in part I the game theoretic model of part II differs in various aspects. First, private monitoring initiatives are assumed to be harmed by pollution, e.g. because of direct health effects or indirectly through depreciation of the value of their homes.[10] Second, the regulator now does not decide whether a firm is allowed to pollute[11]. Instead, he soley decides whether to investigate reports and whether to monitor in the absence of a report. The analysis in part II reveals that implementing a better monitoring device can be accompanied by less compliance, more pollution, and lower welfare due to crowding effects. In that case better private monitoring crowds in public enforcement but crowds out public monitoring. Part II shows that whether a better monitoring technology leads to less pollution mainly depends on the error probability itself.

1.2.3 Regulatory monitoring and prosecutorial enforcement

Contrary to the first two parts, part III does not consider private actors but focuses on the interaction of public monitoring and enforcement and is motivated by recent policy initiatives. Regulation of environmentally harmful activities is often delegated to administrative agencies who can impose administrative sanctions on

[8]See for example http://www.gcmonitor.org; last check on February 13th 2011.

[9]Source: http://yosemite.epa.gov/water/volmon.nsf/Home?openform;
Last check on February 13th 2011.

[10]Nevertheless, the results in part II carry over to the case of unaffected members of such initiatives as long as they are motivated to monitor. Such a motivation could be intrinsic or extrinsic, e.g. they are paid a reward in case they find a violation.

[11]Actually, the model assumes that the harm caused by pollution is sufficiently large so that it is never optimal to allow pollution from a welfare perspective .

violators. One potential shortcoming of administrative sanctions is that they are often limited in size. This gave rise to an increased demand to deem violations of certain environmental regulations as criminal offences. At the European level this resulted in the EU directive 2008/99/EC which prescribes member states to enact an environmental criminal law to harness the strength of harsher sanctioning in order to increase deterrence. Criminalizing certain offences, however, adds a third type of actor to law enforcement, namely public prosecutors. Part III analyzes two effects of this course of action. On the one hand, prosecutors (together with courts) are able to impose higher sanctions. On the other hand, they operate within a specific legal environment. One consequence is that criminal sanctioning does not necessarily consider its implications on firms' incentives to self-report violations. The phenomenon of self-reporting violations, however, is a substantial and valuable element of modern environmental regulation. The analysis in part III asks under which conditions the effect of higher deterrence is dominated by the potentially adverse effect of diluted self-reporting incentives. The principal-agent model shows the conditions under which criminalizing environmental offences has a negative impact on environmental quality.

Taken together, this thesis shows that it is important to acknowledge the presence of third parties in understanding and designing the monitoring and enforcement process. It demonstrates that integrating these actors into the process has the potential to improve on the outcomes. However, it also shows that doing so is not for free but brings about previously overlooked types of cost and can - if not properly assessed - even be counterproductive and make things worse. Thus, this thesis shows that a careful evaluation of the consequences of mobilizing third parties for the monitoring and enforcement process is inevitable before advocating on superiority of trilateral settings.

Part I

Monitoring and Enforcement: The L.B. Jefferies Problem

2 Introduction to part I

From traffic rules to penal law, many of the regulations that restrict the actions of individuals or firms impose uniform rules. In a heterogeneous population, such uniformity leads to considerable differences in the marginal cost of compliance. As a result, aggregate compliance costs will be high.

Explanations for the predominance of uniform rules frequently invoke arguments of equity and fairness in order to justify high aggregate compliance costs. But would uniform rules also be chosen by a policy-maker exclusively interested in efficiency? The answer to this question requires not only an assessment of the costs of uniform standards, but also of the possible benefits that uniform standards provide.[1] The economic literature has identified at least two types of benefits policy-makers can realize by imposing uniform standards: The first type are the significant coordination benefits (Schelling 1978) that can arise from aligning mutual expectations about others' behavior, such as in the case of traffic rules (Lave 1985). The second type of benefits arise at the stage of regulatory design. Landes and Posner (1987), for instance, demonstrate in a tort law context that the 'reasonable person standard' is a response to the considerable resources that would have to be invested in order to design individualized standards. The information costs involved will commonly outweigh the efficiency gains from setting individualized negligence standards.

The purpose of this paper is to demonstrate that there is a third distinct type of benefits from uniformity in regulation that arise at the monitoring and en-

[1]Of course, uniform rules can be corner solutions to the problem of optimal regulation, rendering variations in compliance cost immaterial for rule design. Severe felonies for which no level of welfare gain by the perpetrator outweighs the harm of the crime are a typical example (Posner 1985, Shavell 1993). Focussing on the interesting case this paper considers only those cases where at least for some perpetrators the private benefits exceed the harm caused.

forcement stage. As a specific illustration of these benefits, we show in this paper that uniform regulations are an attractive solution to what the paper terms the 'L.B. Jefferies problem'. Referring to the pivotal character in Hitchcock's (1954) fictional account of bystanders solving a crime,[2] the problem encapsulates the question of *how to make members of the public that are willing and able to report violations to the regulator at a cost to themselves productive for law enforcement.* Evidence for the ability and willingness to report is strong, even when those who report are not themselves directly affected by the violation. Roughly two thirds of crimes in the U.S. have a non-complicit third party present, and reports by third parties bring an additional 230,000 cases to the attention of the police every year (U.S. DoJ 2002). As a whole, reports by third parties are responsible for 40 percent of crimes known to the police (U.S. DoJ 2003). Third-party participation in enforcement is not only evident in the field (see also Kahneman et al. 1986), but also an empirical regularity in laboratory experiments (Turillo et al. 2002, Fehr and Fischbacher 2004, Carpenter and Matthews 2005). Theoretically, Bendor and Mookherjee (1990) show that third-party sanctioning can be part of an equilibrium in an infinitely repeated Prisoner's Dilemma because it can enhance cooperation. From an evolutionary point of view, there is additional evidence that a biological predisposition for third-party punishment can confer evolutionary advantages to groups, and that the share of third-party punishers increases in the size of the society (Marlowe et al. 2008).

Legal scholars have debated different instruments for enhancing reporting of observed violations by non-afffected third parties (Bickman and Helwig 1979, Wenik 1985, Kraakman 1986, Grabosky 1992, and Gilboy 1998). One of the paper's insights is to show that one of the most meaningful instruments, uniformity of rules, may already be in place. In the context of public law enforcement, making rules uniform is productive because it can enable the regulator to reduce monitoring costs by better harnessing citizens' willingness to supply information and thus substitute for own costly monitoring.[3] Regulators that account for the

[2]L.B. Jefferies, the main character in 'Rear Window' (1954) is a successful, but temporarily wheelchair-bound photographer who voyeuristically watches his neighbors from the back window of his apartment.

[3]Cornell Woolrich's plot of 'Rear Window' requires that L.B.Jefferies' monitoring technology is imperfect. The question of technology is the subject of part II.

heterogeneity of compliance costs by individualizing rules do not realize the benefits of such a substitution.

The core of the paper consists of a parsimonious model for capturing the L.B. Jefferies problem and for deriving the conditions under which a regulator would choose a system of uniform rules rather than one that is individualized, i.e. tailored to the individual circumstances of the potential offender. Our results are derived in a sequential game setting[4] involving three parties: One are a large number of heterogeneous agents that can profitably engage in a socially harmful activity, but may violate a rule by doing so. The second party are equally numerous citizens within the population that individually observe one of the agents' action and that are motivated to incur the cost of reporting to the regulator those activities that they expect to be punished. The third party is the regulator that commits to and announces either a uniform rule that treats all agents in the same way or individualized rules that take into account the heterogeneity among agents. The regulator can also choose the volume of (costly) inspections in order to influence compliance, the share of citizens' reports that are investigated at a cost, and the fine for noncompliance. The regulator knows the agents' types, but not their actions while the citizen knows the observed agent's action, but not his type. The three-party setting thus captures salient informational imperfections that are part and parcel of public law enforcement and allows weighing the savings in monitoring costs against enforcement and compliance costs.

Comparing the choice of uniform and individualized rules, the paper's contribution is to show that uniform rules provide a type of benefit that may have been implicitly understood, but that has not been formally analyzed and acknowledged. Since reporting is costly, citizens do not report acts that they believe will not or cannot be punished. A regulator that can credibly commit to treating everyone the same, regardless of the merits of their actions, makes reporting worthwhile to a motivated public, which - in turn - provides effective deterrence against that fraction of offenders that the regulator would otherwise need to monitor at his own expense. The cost of uniformity lies in having to either punish those offenders that the regulator - in an ideal world - would allow committing the act or to

[4]Earlier works that model the regulatory process in a game theoretic way include Russell (1990) and Avenhaus (1992).

deter those same individuals. The latter type of cost leads to high aggregate compliance costs whereas the former type materializes in investigation costs that the regulator has to incur to keep citizens motivated to report infractions. Whether or not the regulator can improve on the uniform policy by individualizing rules depends on the cost structure. Under individualized rules, the regulator needs to rely on his own monitoring because exploiting citizens' reports is 'self-defeating': What would remain in equilibrium in that case is a situation of only those agents committing the act that are allowed to, which renders reporting not a best response for citizens. Monitoring costs therefore push the regulator away from individualized rules. This point can be made stark in the form of a pure-strategy equilibrium in which a sharp tradeoff arises between economizing on monitoring costs and rule-setting: Some of those agents whom society would ideally like to remain unconstrained have to be sacrificed in order for the target share of agents to comply with the law. *In extremis*, efficiency may dictate *to make the 'good guys' do bad to make the 'bad guys' do good.*

The approach of this paper relates to the existing literature in several ways. It is closely related to the theme of information costs facing regulators (Landes and Posner 1985, Laffont and Tirole 1993, Polinsky and Shavell 2000b). While sharing the fundamental concern about how to overcome informational imperfections, the present model deviates from this strand both in terms of the peculiar information structure across the three parties and the non-contractibility of information provision by citizens. Shavell (1993) considers - among other things - how to incentivize the sharing of information by third parties with enforcement agencies, but does not consider the interplay between standard setting and reporting. Arguedas and Rousseau (2009) analyze how regulatory monitoring strategies can lead to efficient outcomes in case of uniform standards but do not incorporate third party monitoring. Other authors within this literature are concerned about the internal organization of law enforcement. Boyer et al. (2000), for instance, study a setting where law enforcers need to be incentivized to pursue violators. While there are some parallels, we differ both in terms of the nature and relationship of our parties and the research question that motivates the inquiry. A second literature that this paper speaks to concerns regulatory policies that make agents self-report (Kaplow and Shavell 1994) or someone with incongruent interests within the agent's organization 'blow the whistle' (Heyes and Kapur 2009a) and thus disclose the hidden action to the regulator on their own. Another literature studies to what extent a small number of agents in an industry can be made to monitor and report on each other (Stiglitz 1990, Varian 1990). In contrast to these papers, our model focuses - in a setting with numerous agents and citizens - on third parties outside the agent's organization and thus on a competing technology for reducing monitoring costs. Finally, the third literature to which this paper relates examines the private enforcement of law (Landes and Posner 1975). In the present paper, the public is also involved, but at a different stage. In common with actual practice, control over enforcement remains with the regulator. Instead, members of the public participate at the monitoring stage only, with the benefits of doing so conditional on regulator action.

The structure of this part is as follows: The following section introduces the set-up of the core model. Section 4 develops the key propositions, followed by a discussion in section 5. Section 6 concludes.

3 The model of part I

The core model features three types of players: a regulator, agents that benefit from committing socially harmful acts, and citizens that are motivated to report illegal behavior to the regulator. The regulatory setting will combine hidden information (the agents' type), hidden action (the agents' action), and constrained communication in a way that makes the L.B. Jefferies problem salient: The regulator in the model knows the agent's type, but not whether he committed the act. This gives rise to hidden action. The citizen observes whether the act has been committed, but does not know the agents' type, thus leading to hidden information. The relationship between the citizens and the regulator is one of noncontractibility and constrained communication: Citizens can report to the regulator that an act has been committed, but cannot be contracted to do so. On the other hand, the regulator cannot inform citizens about the agent's type prior to them reporting. This implies a focus on the interesting situations in which the regulator cannot simply 'tag' types.[1] These modelling choices capture the essence of an enforcement system with heterogeneous agents, motivated, but imperfectly informed citizens, and a constrained regulator. In this setting, the regulator's problem is to choose between individualized rules and uniform rules, and then to enforce those rules such as to maximize the net benefits of regulation, i.e. the difference of private gains incurred by the agents minus harm and enforcement costs.

Two purposes guide the choice of the setting. One is to exclude previously analyzed benefits that can make uniform rules preferable over individualized regulations: Coordination benefits are ruled out by eliminating interaction between

[1] Technologies that force the agent to reveal his type exist in some circumstances (e.g. prison uniforms). For such technologies to be employed, however, requires that they are (i) available, (ii) relatively cheap and (iii) desirable despite their stigmatizing effect.

regulated agents. Moreover, information costs due to hidden information are neutralized by considering a regulator that knows each agent's type. Therefore, if the regulator imposes a uniform rule, other types of benefits must account for the optimality of treating every agent the same. The second purpose is to model a tractable setting that puts the issues into sharp relief. Taken together, the modeling choice and stark simplifications allow scrutinizing the issue of private involvement directly and in isolation, but also provide clear points of departure for future extensions.

3.1 Players and actions

This section specifies the players' available actions. These, the timing of the game and the information sets are also depicted in figure 3.1.

Agents decide whether to commit the act under consideration. Committing the act leads to external social harm h and generates private gross benefits for the agent. For example, the agent could be thought of as a firm that considers dumping waste rather than using proper disposal channels. The population of n agents, with n large, consists of two types of agents, one obtaining benefits θ_L, the other obtaining θ_H, with $\theta_L < \theta_H$. To make the regulatory choice stark, assume initially that $\theta_L < h < \theta_H$ so that it is socially advantageous that high, but not low types commit the act. The distribution of types is common knowledge, i.e. all players know the shares of $\frac{n_L}{n}$ ($\frac{n_H}{n}$) of low (high) types. The choice of an agent is denoted a_i, $i \in \{L, H\}$, with

$$a_i = \begin{cases} 1 & \text{if an agent of type } i \text{ commits the act} \\ 0 & \text{else} \end{cases} . \tag{I.1}$$

Agents have identical finite wealth w with $\theta_H \leq w < \infty$.

The regulator chooses the regulatory policies that apply to the agents. To the regulator, not only the distribution, but the individual type of each agent are known from the outset. The regulatory policies consist of three components: The first is a binary standard that either allows or prohibits the agent from carrying out the action. Denote the standard $\hat{a}_i$, $i \in \{L, H\}$, with

$$\hat{a}_i = \begin{cases} 1 & \text{if the act is allowed for an agent of type } i \\ 0 & \text{else} \end{cases}. \tag{I.2}$$

Given (I.1) and (I.2) an agent violates the norm if $a_i > \hat{a}_i$ or $a_i(1 - \hat{a}_i) = 1$.

The second component is the monitoring strategy, conditional on reports: If no citizen reports a violation by an agent, the regulator commits to inspect that agent with probability p_i. Inspection costs are c_{Ins} and truthfully reveal the action a_i. If there is a report, the regulator investigates the report with probability q_i. Investigation costs are c_{Inv} and also truthfully reveal a_i.

The third component is the enforcement strategy: If inspections detect or investigations confirm a violation, the regulator chooses a fine F_i subject to $F_i \leq w$ so that fines can provide effective deterrence (Shavell 1986). The regulatory policy for an agent of type i is summarized by the tuple $\{\hat{a}_i, p_i, q_i, F_i\}_i$.[2]

The focus of the paper is on the regulator's choice on whether to apply the regulations in an identical way to all agents (*uniform rules*) or to determine the specific setting of the regulations for each agent individually (*individualized rules*). In the two-type setting explored here, individualized rules mean different standards for low and high types or, formally, regulatory policies of types $(\{1, p_L, q_L, F_L\}_L, \{0, p_H, q_H, F_H\}_H)$ or $(\{0, p_L, q_L, F_L\}_L, \{1, p_H, q_H, F_H\}_H)$. Under uniform regulations both types face the same standard, the same monitoring and the same enforcement strategy[3]: The regulatory policy is $\{0, p, q, F\}$ or $\{1, p, q, F\}$[4] for all agents. The regulator then announces these policies publicly.

Citizens are the third type of players. The risk-neutral and identical citizens can be thought of as clones of L.B. Jefferies within the population: Members of the general public watching their personal environment as they go about their

[2]Restricting the regulator to a fixed fine of an amount sufficient to provide full deterrence provides an alternative modelling strategy. This common assumption, however, deprives the analysis of a subtlety: As we show below, there exists an equilibrium in which the fine must also be *sufficiently small* to ensure non-compliance.

[3]We relax the assumption that uniform standards have to be accompanied by uniform monitoring and enforcement choices in section 4.3.

[4]For simplicity we omit the subscript if a policy is uniform and set it into brackets if an expression applies to both individualized and uniform policies.

daily lives. In order to collapse what is a dynamic process of observing and detecting into a static setting, we consider as a benchmark the stylized case of n citizens being randomly matched one-to-one with n agents at the time when the agent commits the act or not. Citizens observe a_i at zero cost. However, due to random matching, the citizen does not know the type i of the agent whose act he observes.

The randomized one-to-one mapping between citizens and agents purposefully abstracts from citizens purposefully gathering information across several agents. It also precludes free-riding because every agent's decision is observed by only one citizen.[5] Further, citizens are endowed with a perfect monitoring technology, i.e. every citizen identifies exactly whether 'his' agent has committed the act.

The decision of a citizen whether to report is denoted r with

$$r = \begin{cases} 1 & \text{if the citizen reports} \\ 0 & \text{else} \end{cases} .$$

Being risk-neutral, a citizen will file a report about an incidence if and only if the expected benefits are at least as great as the costs of reporting, to which we turn now.

The literature suggests different reasons why reporting crimes is *costly*. The two most obvious ones are the expense and time of filing a report with a regulator, e.g. the police. Many jurisdictions require this to be done in person and following a certain protocol, thus raising costs. There are also information costs involved in determining the correct regulator to approach with a report (police, FDA, EPA, etc.). Finally, if the report results in enforcement actions, a citizen may have to spend additional time in court as a witness. Other reasons cited in the literature are fear of self-incrimination (Garoupa 2001) and fear of reprisals (Singer 1988, Walker et al. 2009). The parameter c_R subsumes these costs into a single measure.

There are three main explanations for the immaterial *benefits* of reporting.

[5]See Harrington, Jr. (2001) and Osborne (2009, pages 131-132) for simple games where more than one person can help a victim or report an observed crime to the police. They show that the probability that no one helps (reports) increases in group size. See also Latané and Nida (1981) for a review on this issue.

A related question is whether to impose a duty to rescue. Harnay and Marciano (2009) provide a non exhaustive review of analyses of rescue laws.

One is that it generates benefits to those reporting by helping prevent harm to others and themselves (Shavell 1993). A second explanation are the psychological rewards of contributing to the punishment of wrongdoers, a motive often labeled as 'retribution' or 'thirst for revenge' (Wittman 1974, Posner 1980, Shavell 1993). Thirdly, Posner (1980) and Heyes and Kapur (2009a) point out that individuals feel a 'moral duty' to report crimes. All three aspects are borne out in the field and in the lab. Survey evidence (U.S. DoJ 2008) among citizens reporting crime finds an overwhelming presence of the harm prevention argument (53.2 percent), strong evidence for a moral duty to report (22.1 percent), and clear evidence for a retribution motive (6.5 percent). Laboratory experiments on third-party punishment corroborate these findings: Individuals that can observe, but are not directly affected by wrongful acts have a significant willingness to pay for ensuring that offenders are sanctioned (Turillo et al. 2002, Fehr and Fischbacher 2004, Carpenter and Matthews 2005). The immaterial benefits B from reporting a violation that will be punished with certainty are summarized by the parameter b. For motivated citizens to be productive in monitoring requires that - at a minimum - those unconditional benefits of reporting exceed the cost of doing so, i.e. $b \geq c_R$. Modeled in this way, citizens are "norm-takers" in the sense that the benefits of reporting are not conditional on the agent's type. Welfare-oriented citizens, on the other hand, may well want to restrict reporting to those agents that impose a net harm on society (i.e. low types) such that benefits are now conditioned on type, e.g. $B(\theta_L) = b$ whereas $B(\theta_H) \leq 0$. We initially retain the norm-taker assumption, which gives rise to richer characterization of equilibria, before demonstrating in section 4.3 that the equilibrium with welfare-oriented citizens follows from these results in a natural way.

The harm prevention and retribution motives of citizens, on which this paper builds, render the benefits of reporting *conditional on the subsequent behavior* of the regulator. The most salient dimension of regulator response is whether further enforcement action is undertaken. Such enforcement might be withheld because the act that was reported turns out to be not illegal upon investigation or because the regulator fails to follow up on a report. The likelihood of subsequent enforcement after reporting therefore matters for the reporter's benefit. Theory (Heyes and Kapur 2009a, Mokherjee and Png 1992), experiments (van Soest and

Vyrastekova 2009), and empirical evidence (MacDonald 2001) highlight that a decrease in the perceived likelihood of subsequent enforcement action is associated with a reduction in the incentives to report. This is underlined by survey evidence on reporting behavior in both the US (U.S. DoJ 2008) and the UK (Walker et al. 2009): Uncertainty over whether a person's act did or did not constitute an offence and over subsequent police efforts are cited as an important reason for not reporting. Other studies show that the propensity to report criminal activities to the police depends on the size (Levitt 1998) and the productivity (Soares 2004) of enforcement institutions, but less so on external pecuniary rewards (Bickman and Helwik 1979).

Taken together, the motivated citizens in this model take their decision on whether or not to report on the basis of unconditional costs and conditional benefits. We now turn to the objectives and payoffs of the citizens and the other two players that determine that decision before explaining the timing of decisions.

3.2 Objectives and payoffs

The players' objectives and the strategic interaction between players determine their payoffs and therefore the optimal choice among the options for action set out above.

Agents maximize expected net benefits from committing the act. Given the citizen's choice and the regulatory policy, expected net benefits for an agent of type i are

$$\pi_i = a_i \left[\theta_i - \left(1 - \hat{a}_{(i)}\right) \left(rq_{(i)}F_{(i)} + (1-r)\, p_{(i)}F_{(i)}\right)\right].$$

If an agent commits the act ($a_i = 1$) he receives gross benefits θ_i. If $a_i = 1$ and the act is not allowed ($1-\widehat{a}_{(i)} = 1$) an agent has to pay the fine $F_{(i)}$ either when being inspected with probability $p_{(i)}$ if his act is not reported ($1-r = 1$) or when being investigated with probability $q_{(i)}$ if he gets reported ($r = 1$). Since $\theta_i > 0$, if the act is allowed ($\widehat{a}_{(i)} = 1$) or in the absence of enforcement ($rq_{(i)} + (1-r)\, p_{(i)} = 0$), an agent will always choose $a_i = 1$.

The regulator's mandate is to maximize the value of his policy V, which is the difference between the net benefits of regulation and its enforcement costs for each agent V_i, aggregated over all $n = n_H + n_L$ agents. Policies are at most differentiated by type: Agents of the same type face the same regulatory policy. Given a type i agent's decision and citizens' reporting choices, the contribution V_i of one agent of type i to V is

$$V_i = a_i\left(\theta_i - h\right) - rq_{(i)}c_{Inv} - \left(1 - r\right)p_{(i)}c_{Ins}.$$

If the act is committed, V_i comprises the private gross benefits to the agent and harm to the public. In case of a report the regulator incurs investigation costs with probability $q_{(i)}$, otherwise he bears the expected inspection costs. Since citizens are identical, the optimal a_i is the same for all agents of type i. In aggregating, therefore, the regulator's criterion V becomes the sum of the differences by type, weighted by the respective population:

$$V = \sum_{i=L,H} n_i V_i.$$

As in practice, net benefits of reporting at the level of the citizen are not part of the regulator's mandate (Heyes and Kapur 2009a). Given V, the regulator needs to choose between a uniform policy that treats both types the same or an individualized policy.

A citizen observing an action a_i receives net utility from reporting $b - c_R$ whenever he reports an illegal act that is subsequently investigated. A report on a legal act leads only to costs for a citizen. Thus, utility u for citizens is

$$u = r\left[a_i\left(1 - \hat{a}_{(i)}\right)q_{(i)}b - c_R\right].$$

The tie-breaking rule adopted is that in case of indifference a citizen reports, an agent complies with a ban and the regulator allows commmitting the act.

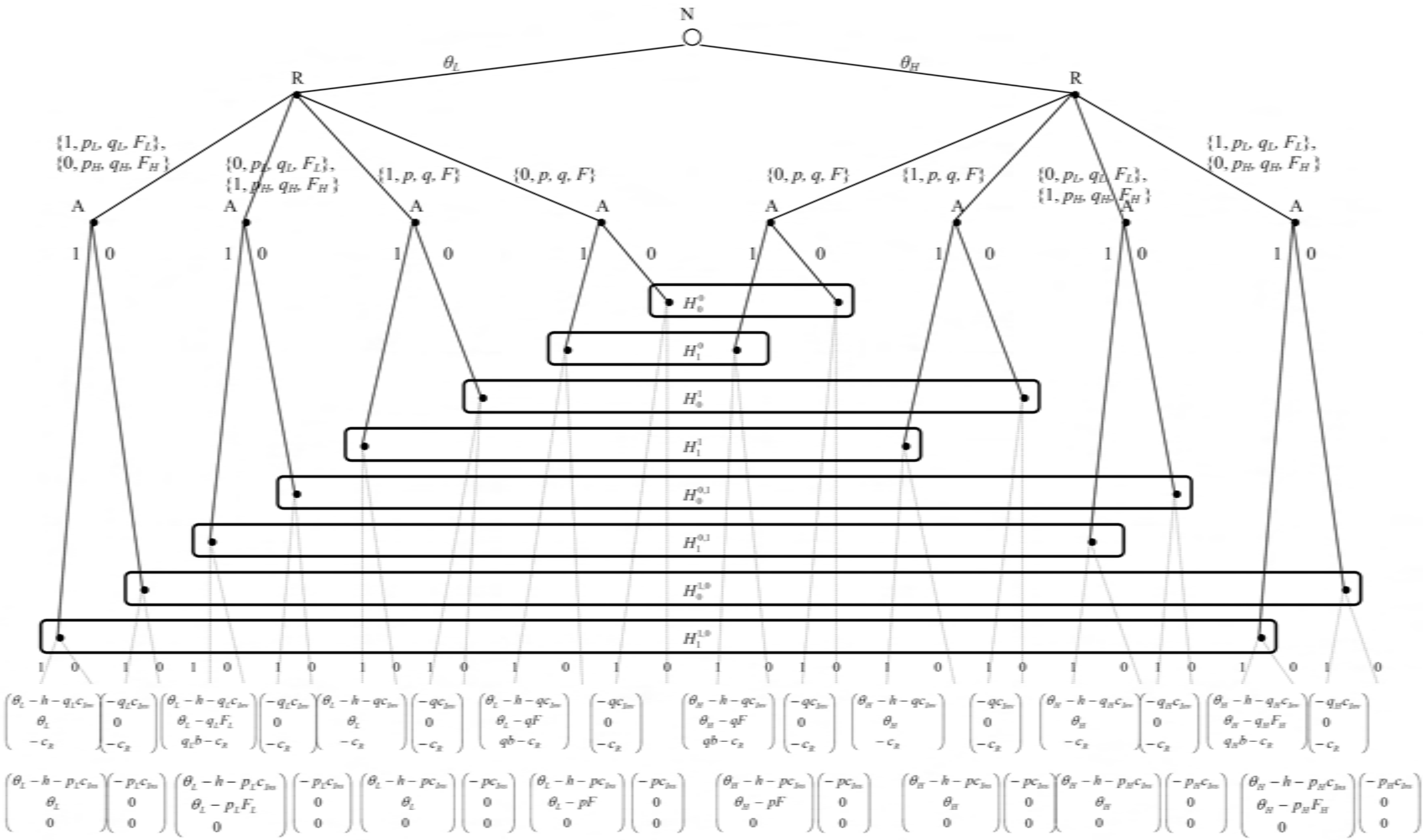

Figure 3.1: The Game Tree.

3.3 Timing

The most intuitive depiction of the game tree for the regulator's problem of setting uniform or individualized policies across n agents is to draw the tree from a single citizen's point of view. Figure 3.1 shows that tree. The tree captures one of n subproblems that yields a value V_L (V_H) if nature chose a low (high) type. The regulator's problem is to maximize the value of his policy across all n subproblems by deciding on a policy that conditions on the type chosen by nature or treats all types the same.

From a citizen's point of view, the game starts with nature randomly assigning an agent to every citizen. For the citizen, the only payoff relevant question is the type of agent that nature matched him with. As he has no information about any agents' type, the relevant probability of facing a low (high) type is $\frac{n_L}{n}$ ($\frac{n_H}{n}$).[6]

Second, the regulator - knowing each agent's type, but not the random assignment - specifies the regulatory policies for all agents simultaneously. The policies are announced and become public knowledge.

Third, observing their type and the regulator's decision, agents choose whether to commit the act. Finally, citizens decide whether to report. A citizen knows whether the agent assigned to him committed the act and the regulatory policy. The only thing a citizen does not know is of which type i the agent is. This information structure is mirrored in the notation of the citizen's information sets: An information set is denoted $H^{\hat{a}}_{0,1}$ after a uniform policy and $H^{\hat{a}_L,\hat{a}_H}_{0,1}$ after an individualized one where the subscript is one if the citizen observes an act and is zero otherwise. Not explicitly shown is the precommitted enforcement by the regulator to finding firms non-compliant either by investigation following a report or through a random inspection.

[6]This is, naturally, not true at the aggregate level: With $n_i > 0$ for both $i = \{L, H\}$,the different assignments of types to citizens are not independent at the aggregate level.

4 Results

Having laid out the components of the game we now derive the solution to the sequential game. The equilibrium concept employed here is perfect Bayesian equilibrium (PBE) in pure strategies, with no restrictions on beliefs off the equilibrium path. As we consider only pure strategies deriving the respective systems of beliefs is straightforward and arises naturally in what follows. We focus on pure strategy equilibria at the expense of mixed strategies to derive the starkest results.

4.1 Citizens' and agents' equilibrium choices

Starting at the last decision stage of the game, the citizen decides whether to report. The citizen knows the agent's decision a_i and the regulatory policy but not the type of the agent he faces. As a_i is a binary variable and the regulator can choose between four different kinds of policies the game can reach eight information sets. At four of these sets the citizen observes that the act was not committed and sequential rationality requires no report because $c_R > 0$. Thus, in a PBE the citizen's play at information sets $H_0^0, H_0^1, H_0^{0,1}$ and $H_0^{1,0}$ is $r = 0$. At the other four information sets the citizen knows that the act was committed. If additionally the regulator set a uniform policy the optimal choice is unambiguous: At H_1^1, i.e. the act is allowed for all agents, not to report is optimal, so the equilibrium play is ($r = 0$ if H_1^1). If instead the act is uniformly banned, i.e. the game reached H_1^0, the payoff from reporting is $qb - c_R$ compared to zero from not reporting, thus in equilibrium the citizen plays $\left(r = 0 \text{ if } H_1^0,\ q < \frac{c_R}{b}\right)$ and $\left(r = 1 \text{ if } H_1^0,\ q \geq \frac{c_R}{b}\right)$. Contrary, at the two remaining information sets where $a_i = 1$ and the regulator imposed individualized policies, the citizen's pay-off does not only depend on a_i and the policy chosen but also also on the - unknown - agents' type and thus on the node reached. If $\hat{a}_i = 0$ the pay-off from reporting would be $q_i b - c_R$ whereas if $\hat{a}_i = 1$ the citizen only incurred the costs c_R without realizing benefits. The equilibrium actions at $H_1^{1,0}$ and $H_1^{0,1}$ therefore depend on the agents' and the regulator's equilibrium strategies.

At the penultimate stage the agent who knows his type and the regulatory policy decides whether to commit the act. The act can be allowed or banned. If it is allowed the agent will commit the act because $\theta_i > 0$. Therefore, in equilibrium an agent plays $a_i = 1$ if $\left\{1, p_{(i)}, q_{(i)}, F_{(i)}\right\}_{(i)}$. Whether an agent complies with a ban depends on the citizen's strategy and the regulator's monitoring and enforcement strategy. He complies with a ban whenever committing the act yields a negative pay-off. The ban can either be uniform or part of an individualized policy. Under a uniform ban the agent's equilibrium play is unambiguous because the citizen's equilibrium play following a uniform policy is also unambiguous. In equilibrium a type i agent's play is ($a_i = 0$ ($= 1$) if $\left\{0, p, q < \frac{c_R}{b}, F\right\}$, p, F s.t. $\theta_i - pF \leq 0$ (> 0)) and ($a_i = 0$ ($= 1$) if $\left\{0, p, q \geq \frac{c_R}{b}, F\right\}$, q, F s.t. $\theta_i - qF \leq 0$ (> 0)). Contrary, if the ban is part of an individualized policy, an agent's equilibrium strategy also depends on that of the citizen and is

$$\left(a_i = 0 \ \ (= 1) \ \text{ if } \ \{0, p_i, q_i, F_i\}_i \,, \ \ p_i, F_i \text{ s.t. } \theta_i - p_i F_i \leq 0 \ \ (> 0)\right)$$

if the citizen plays $\left(r = 0 \text{ if } H_1^{\hat{a}_i=0, \hat{a}_{-i}=1}\right)$ and

$$\left(a_i = 0 \ \ (= 1) \ \text{ if } \ \{0, p_i, q_i, F_i\}_i \,, \ \ q_i, F_i \text{ s.t. } \theta_i - q_i F_i \leq 0 \ \ (> 0)\right)$$

if $\left(r = 1 \text{ if } H_1^{\hat{a}_i=0, \hat{a}_{-i}=1}\right)$.

Having analyzed choices at the last two decision stages we can now turn to the key part of the paper which characterizes the regulator's choice of policy at the first stage.

4.2 Equilibrium policies

Based on the characterizations of citizens' and agents' behavior, we can now derive proposition I.1 that defines the optimal regulatory policy. To identify the optimal policy we apply a heuristic strategy that distinguishes between policies that lead to identical or different behavior by agents of different types. We derive the regulator's payoff for every possible equilibrium policy and then compare these outcomes to determine the optimal policy.

4.2.1 Policies that induce identical behavior

As a start we consider policies that induce identical behavior by all agents. The two equilbrium policies possible are a uniform permit and a uniform ban with full enforcement. If the regulator uniformly permits the act both types commit it. Because citizens then do not report and no fines are imposed, the investigation probability and the fine do not affect any player's payoff and are therefore arbitrary. The inspection probability affects V negatively and is thus set equal to zero. As a result a uniform permit yields

$$V\left(\{1,0,q,F\}\right)=n_H\left(\theta_H-h\right)-n_L\left(h-\theta_L\right). \tag{I.3}$$

One implication of (I.3) is that in the absence of a uniform permit p, q and F must be set such that at least one type does not commit the act: If both types commit the act the regulator's pay-off is

$$V=\sum_{i=L,H}n_i\left(\theta_i-h-rq_{(i)}c_{Inv}-(1-r)\,p_{(i)}c_{Ins}\right)$$

which is maximized for $p_{(i)}=0$ (if $r=0$) and $q_{(i)}=0$ (if $r=1$). But the outcome is then the same as in (I.3) and by assumption the regulator then allows the act. As a consequence, in equilibrium an individualized policy does not induce identical behavior by all agents.[1]

The other policy inducing identical behavior is the fully enforced uniform ban.

[1] Naturally, as an individualized policy has $\hat{a}_i=1$ for one type and $a_i=1$ is then the optimal choice, an individualized policy also cannot induce $a_i=0$ for both types.

This policy yields $V = 0$ as the lower bound for the regulator's equilibrium pay-off: The regulator can ensure a non-negative outcome by enforcing a uniform ban at no costs. A sufficiently high investigation probability together with a sufficiently high fine, e.g. $q = 1$ and $F = w$, guarantee compliance by both types. A violation would be reported and the agent would get the negative pay-off $\theta_i - w$. As all agents comply, there are no reports and thus no investigations. Regulatory inspections would only lead to costs because deterrence is provided by the threat of a report. The optimal inspection probability is thus zero and the regulator realizes

$$V(\{0, 0, 1, w\}) = 0. \tag{I.4}$$

A consequence of (I.4) is

Lemma I.1 *A policy inducing $a_L = 1$ and $a_H = 0$ is not a possible equilibrium outcome.*

Proof. An individualized policy inducing $a_H = 0$ must have $\hat{a}_H = 0$ and $\hat{a}_L = 1$. The regulator's payoff then is

$$V(\{1, p_L, q_L, F_L\}_L, \{0, p_H, q_H, F_H\}_H) =$$
$$-n_L(h - \theta_L + rq_L c_{Inv} + (1 - r) p_L c_{Ins}) - n_H p_H c_{Ins}.$$

Similar, a uniform policy inducing $\hat{a}_H = 0$ must have $\hat{a} = 0$ yielding

$$V(\{0, p, q, F\}) = -n_L(h - \theta_L + rqc_{Inv} + (1 - r) pc_{Ins}) - n_H pc_{Ins}.$$

Because $h - \theta_L > 0$ both expressions are negative, but (I.4) shows that the minimum equilibrium payoff for the regulator is zero. ■

4.2.2 Policies that induce different behavior

So far, we considered policies that induce identical behavior by all agents. The lemma that follows from the fully enforced uniform ban directly applies to the analysis of policies that induce different behavior and is the basis for the following analysis. It demonstrates that we can focus our attention on policies inducing $a_L = 0$ and $a_H = 1$.

To induce different behavior the regulator can choose an individualized policy or enforce a uniform ban only partially. Consider first the case of an individualized policy. The lemma shows that an individualized policy with $\hat{a}_L = 1$ and $\hat{a}_H = 0$ is not a possible equilibrium choice as it yields $a_L = 1$. Therefore, the equilibrium play cannot reach the information set $H_1^{1,0}$ and the citizen's equilibrium play at $H_1^{1,0}$ can be $r = 0$ or $r = 1$. Alternatively, the regulator can set $\hat{a}_L = 0$ and $\hat{a}_H = 1$. Suppose that the citizen does not report an observed act under an individualized policy with $\hat{a}_L = 0$ and $\hat{a}_H = 1$, i.e. the citizen plays $r = 0$ at $H_1^{0,1}$. High types then commit the act and are not reported. They contribute $V_H = \theta_H - h - p_H c_{Ins}$ to V and the optimal inspection probability is zero. The fine F_H is never imposed and is - as well as the investigation probability q_H - arbitrary. The ban for low types must be enforced through monitoring because the citizen plays $r = 0$ at $H_1^{0,1}$. Low types contribute $V_L = -p_L c_{Ins}$ and the regulator will set the minimal inspection probability necessary to deter them. They comply if $\theta_L - p_L F_L \leq 0$ or $p_L \geq \frac{\theta_L}{F_L}$. This is minimized for $F_L = w$ and $p_L = \frac{\theta_L}{w}$.[2] The investigation probability q_L is arbitrary and the outcome for the regulator is

$$V\left(\left\{0, \frac{\theta_L}{w}, q_L, w\right\}_L, \{1, 0, q_H, F_H\}_H\right) = n_H(\theta_H - h) - n_L \frac{\theta_L}{w} c_{Ins}. \tag{I.5}$$

Consider second that the regulator enforces a uniform ban only partially to induce different behavior of agents. A uniform policy that does not rely on citizen reporting, i.e. $q < \frac{c_R}{b}$, to enforce the ban only for low types is not a possible equilbrium outcome: If $q < \frac{c_R}{b}$ the citizen will not report an observation and the regulator maximizes $V = n_H(\theta_H - h) - npc_{Ins}$ subject to $\theta_L - pF \leq 0$, $\theta_H - pF > 0$ and $F \leq w$. Thus he sets $F = w$ and $p = \frac{\theta_L}{w}$ yielding $V\left(\left\{0, \frac{\theta_L}{w}, q < \frac{c_R}{b}, w\right\}\right) = n_H(\theta_H - h) - n\frac{\theta_L}{w} c_{Ins}$ which is a smaller than that for (I.5). Conversely, the regulator can rely on reports and thus sets $q \geq \frac{c_R}{b}$. The policy must also satisfy $\theta_L - qF \leq 0$ and $\theta_H - qF > 0$ to enforce the ban partially. So $\max\left\{\frac{c_R}{b}, \frac{\theta_L}{F}\right\} \leq q < \frac{\theta_H}{F}$ must hold. Since citizens report the acts committed by high types, the regulator receives $V = n_H(\theta_H - h - qc_{Inv}) - n_L pc_{Ins}$. Inspections lead to costs

[2]Note that $\left(r = 0 \text{ if } H_1^{0,1}\right)$ is then sequential rational for the citizen as regulatory inspections guarantee that only high types being allowed commit the act.

without providing deterrence and $p = 0$ is optimal. Now, the expression for V is maximal if q is minimal. If $\frac{c_R}{b} \leq \frac{\theta_L}{w}$ it is optimal to set $F = w$ and $q = \frac{\theta_L}{w}$. If instead $\frac{c_R}{b} \geq \frac{\theta_L}{w}$ the regulator has to choose $q = \frac{c_R}{b}$ and he sets the fine F such that $\theta_L - \frac{c_R}{b} F \leq 0$ and $\theta_H - \frac{c_R}{b} F > 0$ are satisfied. Without loss of generality let $F = \theta_L \frac{b}{c_R}$. Therefore, if the regulator relies on citizen reporting to enforce a uniform ban partially his pay-off is

$$V\left(\left\{0, 0, \frac{\theta_L}{w}, w\right\}\right) = n_H\left(\theta_H - h\right) - n_H \frac{\theta_L}{w} c_{Inv} \tag{I.6}$$

if the deterrence criterion is fulfilled, that is $\max\left\{\frac{c_R}{b}, \frac{\theta_L}{w}\right\} = \frac{\theta_L}{w}$ and

$$V\left(\left\{0, 0, \frac{c_R}{b}, \theta_L \frac{b}{c_R}\right\}\right) = n_H\left(\theta_H - h\right) - n_H \frac{c_R}{b} c_{Inv} \tag{I.7}$$

if the reporting criterion is fulfilled, that is $\max\left\{\frac{c_R}{b}, \frac{\theta_L}{w}\right\} = \frac{c_R}{b}$.

Given that the citizen does not report an observed act under an individualized policy, i.e. he plays $r = 0$ at $H_1^{0,1}$, the previous analysis of policies is an exhaustive characterization of equilibrium outcomes for the regulator. Comparing the outcomes in (I.3) - (I.7) leads to propositions I.1 and I.2 which establish the existence and uniqueness (see the appendix for the proof of uniqueness) of the optimal choice by the regulator.

Proposition I.1 *(Existence) The regulatory game has an equilibrium in pure strategies where in equilibrium, the citizen plays* $\left(r = 0 \text{ if } H_1^{0,1}\right)$. *The equilibrium policy is*

(FB) $\{0, 0, 1, w\}$ *with* $V = 0$ *if* $\underline{c} = n_H\left(\theta_H - h\right)$,

(UP) $\{1, 0, q, F\}$ *with* $V = n_H\left(\theta_H - h\right) - n_L\left(h - \theta_L\right)$ *if* $\underline{c} = n_L\left(h - \theta_L\right)$,

(TP) $\left(\left\{0, \frac{\theta_L}{w}, q_L, w\right\}_L, \{1, 0, q_H, F_H\}_H\right)$ *with* $V = n_H\left(\theta_H - h\right) - n_L \frac{\theta_L}{w} c_{Ins}$ *if* $\underline{c} = n_L \frac{\theta_L}{w} c_{Ins}$,

(PBD) $\left\{0, 0, \frac{\theta_L}{w}, w\right\}$ *with* $V = n_H\left(\theta_H - h\right) - n_H \frac{\theta_L}{w} c_{Inv}$ *if* $\underline{c} = n_H \frac{\theta_L}{w} c_{Inv}$ *and*

(PBR) $\left\{0, 0, \frac{c_R}{b}, \theta_L \frac{b}{c_R}\right\}$ *with* $V = n_H\left(\theta_H - h\right) - n_H \frac{c_R}{b} c_{Inv}$ *if* $\underline{c} = n_H \frac{c_R}{b} c_{Inv}$

where

$$\underline{c} = \min\left\{n_H(\theta_H - h); n_L(h-\theta_L); n_L\frac{\theta_L}{w}c_{Ins}; \max\left\{n_H\frac{\theta_L}{w}c_{Inv}; n_H\frac{c_R}{b}c_{Inv}\right\}\right\}.^3$$

The questions what happens if citizens play $r = 1$ at $H_1^{0,1}$ and whether the policies chosen as stated in proposition I.1 are unique are adressed in

Proposition I.2 *(Uniqueness) For all parameter constellations the rules chosen in equilibrium are unique.*

The key to understanding proposition I.1 is the minimum cost criterion $\underline{c}$ that trades off the different types of enforcement costs and the harm from crime. This criterion determines which of the five possible equilibrium outcomes is optimally chosen by the regulator. Of the five outcomes, only one, namely TP, is characterized by a tailored policy that is sensitive to differences between types. It is also the only outcome in which the regulator chooses to monitor himself. The four other outcomes are characterized by a uniform standard, even though they are uniform in different ways and for different reasons: Outcome FB involves a fully enforced ban and arises when the costs of uniformity are low on account of low total benefits from high types, either because n_H is low or because θ_H is close to h. Outcome UP is characterized by uniformly permitting the act and arises when the harm avoided through regulation is small. Outcome PBD involves a partially enforced ban whose investigation intensity is determined by the deterrence criterion because $\frac{\theta_L}{w} > \frac{c_R}{b}$. Outcome PBR on the other hand involves a partially enforced ban whose investigation intensity is determined by the reporting criterion because $\frac{c_R}{b} > \frac{\theta_L}{w}$.

The key insights of proposition I.1 can be illustrated graphically. Graphs (a), (b), and (c) show the geometry of outcomes defined by proposition I.1 in $\left(\theta_L, \frac{n_H}{n_L}\right)$-space for different parameter constellations. The graphs capture three combinations of investigation and reporting costs: Graph (a) shows the case of high investigation costs in the presence of low reporting costs, graph (b) the case

[3] Given the assumption that the indifferent regulator allows the act, then if $\underline{c}$ is not unique the regulator chooses $\{1, 0, q, F\}$ if $\underline{c} = n_L(h - \theta_L)$. If $n_L(h-\theta_L) \neq \underline{c}$ the regulator chooses $\left(\left\{0, \frac{\theta_L}{w}, q_L, w\right\}_L, \{1, 0, q_H, F_H\}_H\right)$ if $\underline{c} = n_L\frac{\theta_L}{w}c_{Ins}$. If additionally $n_L\frac{\theta_L}{w}c_{Ins} \neq \underline{c}$ the regulator's choice cannot be further isolated without additional assumptions.

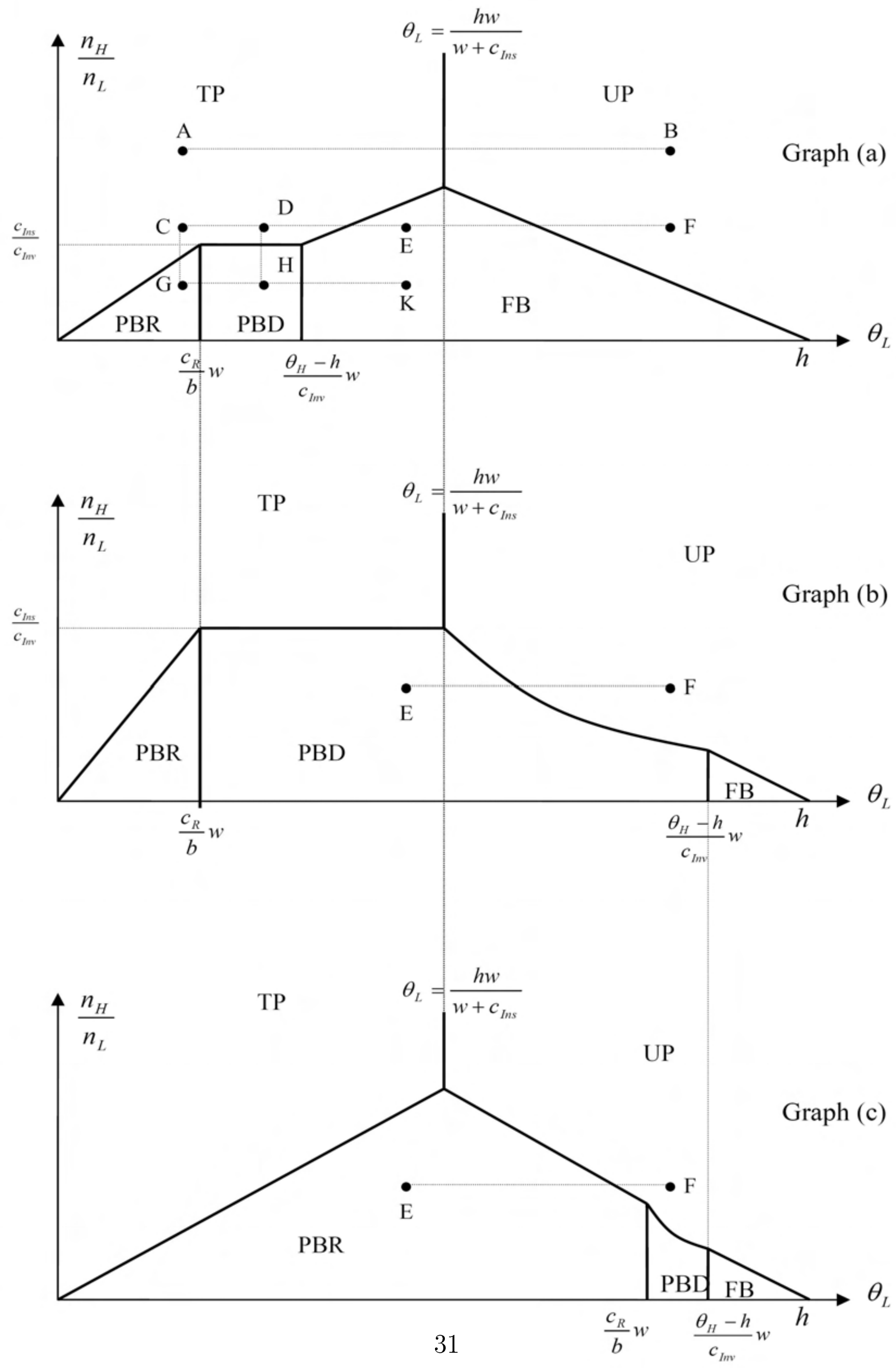

Figure 4.1: Equilibrium Policies.

of low investigation costs and low reporting costs, and graph (c) the case of low investigation costs and high reporting costs. The case of high investigation and high reporting costs does not merit a dedicated discussion.[4] Given the minimum cost criterion $\underline{c}$, the relative position and size of the five regulatory outcomes arise in an intuitive way. The relative position of FB, UP, TP, PBD, and PBR in $\left(\theta_L, \frac{n_H}{n_L}\right)$-space captures the fact that the minimium cost criterion $\underline{c}$ depends positively on n_H for FB, PBD, and PBR and positively on n_L for UP and TP. Therefore, if the population contains a large number of high types, the outcome must be UP or TP since total investigation costs would otherwise be excessive (PBR and PBD) or too many high type benefits are forfeited (FB).

The equilibria with a uniform ban, i.e. FB, PBD, and PBR, occur only for a relatively small fraction of high types. The specific outcome depends on low type benefits. Consider first outcomes PBD and PBR. Which outcome prevails depends on whether the reporting or the deterrence criterion holds. In case of reporting criterion, a minimum fraction of violators has to be sanctioned to incentivize citizens to report. For a small θ_L this minimum fraction exceeds the minimum investigation probability that provides sufficient deterrence and vice versa. Thus, if θ_L is small (large), PBD (PBR) cannot occur. Because both investigation probabilities do not depend on the number of low and high types, the boundary is a vertical line. Compare now outcomes FB and PBD. Enforcement costs under PBD, i.e. investigation costs for high types, depend on the investigation frequency. Enforcement costs under FB, on the other hand, are zero as deterrence for all agents is provided by the threat of facing a report. Because in PBD, investigation costs increase in θ_L, PBD dominates FB for small low type benefits and vice versa. Note that under both policies low types are deterred and so the regulator compares investigation costs for high types and

[4]See the appendix for the derivation of the graphs. The graphs presented are derived for the case $n_H \frac{c_R}{b} c_{Inv} < n_H (\theta_H - h)$. This does neither depend on θ_L nor on n_H nor on n_L and so it cannot be displayed in the $\left(\theta_L, \frac{n_H}{n_L}\right)$-space.

For the reverse case with high reporting and high investigation costs - $n_H \frac{c_R}{b} c_{Inv} > n_H (\theta_H - h)$ - the graph looks similar to the bottom one. However, equilibria PBR and PBD cannot occur: First, PBR cannot be the outcome because $n_H \frac{c_R}{b} c_{Inv} > n_H (\theta_H - h)$. Second, PBD cannot be the outcome because this requires $n_H \frac{\theta_L}{w} c_{Inv} > n_H \frac{c_R}{b} c_{Inv}$ but then also $n_H \frac{\theta_L}{w} c_{Inv} > n_H (\theta_H - h)$ holds. If $n_H \frac{c_R}{b} c_{Inv} > n_H (\theta_H - h)$ in the middle lower area equilibrium FB prevails.

forfeiting high types' benefits. Which of these yields higher losses does not depend on the number of low and high types and so the boundary is a vertical line. Summing up, if the relative number of high types is sufficently small, the uniform ban is partially enforced if θ_L is small and is fully enforced otherwise. Therefore, PBR prevails in the lower left part of the graph, PBD in the lower middle one, and FB in the lower right section.

Comparing the graphs captures how the relative position and size of the outcomes change as reporting and investigation costs change. Graph (b) captures a situation with lower investigation costs relative to graph (a). This difference renders a reliance on reporting cheaper from the regulator's point of view and decreases the parameter space over which TP is chosen. At the same time, use of partially enforced bans increases, with PBR increasing at the expense of TP and PBD increasing at the expense of all other non-partial outcomes. This reflects the lower cost of access to investigations as an enforcement device. Comparing graphs (b) and (c), the increase in reporting costs reduces the attractiveness of relying on citizens for θ_L small because inspections become relatively cheaper compared to the increased reporting criterion until the regulator becomes indifferent between TP and UP. The changes between PBR, PBD, and UP are subtle and are discussed in detail below.

To complete the characterization, it is useful to understand more about how the regulatory outcomes change in response to changes in θ_L and $\frac{n_H}{n_L}$, the axes of graphs (a) through (c). Starting with graph (a), consider points A and B, located in the TP and UP areas, respectively. Starting at point A, where θ_L is small and the fraction of high types is large, and traveling towards B, we see an increase in θ_L leading to low type *net* damages decreasing and inspection costs increasing. At some point, therefore, we cross the boundary beyond which it becomes optimal to allow the act for low types as well (point B). Keeping θ_L constant at the level of A, but decreasing the fraction of high types, we arrive at point C where the outcome is still TP. Increasing θ_L at these shares of high types to low types in the direction of E, the regulator's trade-off differs from the previous one: Instead of trading off inspection costs and low type net damages, he now trades off inspection costs and forfeiting high type benefits. Because the fraction of high types is now smaller, it becomes profitable to forfeit the benefits and fully enforce the uniform ban.

The equilibrium becomes FB as in point E. The boundary between FB and TP is increasing in θ_L: A rising θ_L makes inspections less attractive but can be offset by an increase in the number of high types, thus making FB less attractive. If θ_L increases further from E, inspection costs do not increase because no inspections are carried out while low type net damages continue to fall. Then forfeiting high type benefits is no longer optimal but incurring low type net damages is. Thus UP becomes the optimal policy (point F). The boundary between FB and UP is decreasing in θ_L because an increase in θ_L, making UP attractive, can be offset by a decrease in the number of high types as this decreases benefits forfeited under FB.

Decreasing the fraction of high types at C and D further, relative investigation costs under partial enforcement also decrease. A ban for low types can then be enforced through investigations of high types at lower costs compared to inspections and thus PBR and PBD become the optimal choice (points G and H). Moving from C to G, the boundary between TP and PBR is increasing in θ_L because an increase in θ_L, rendering inspections less attractive, can be offset by an increase in n_H, which - in turn - increases total investigation costs. Moving from D to H, the boundary between TP and PBD is a horizontal line as in both outcomes the probability of punishment that deters low types is the same: In TP, low types get *inspected* whereas in PBD, high types get *investigated* which provides the deterrence for the low types. Thus, the boundary equals the fraction of inspection costs and investigation costs, $\frac{c_{Ins}}{c_{Inv}}$. Moving from H to K increases the investigation costs, which - beyond the boundary - exceed high type benefits that are forfeited under FB (point K).

In Graph (b), point E is now located in outcome PBD on account of the lower investigation costs. Increasing θ_L now leads to increases in investigation costs, in contrast to graph (a) because E now involves actual investigations. At the same time, low type net damages decrease so that the regulator prefers UP, under which he incurs these damages rather than investigation costs (point F). The new boundary separating UP and PBD is decreasing in θ_L because an increase in θ_L, making UP more attractive, can be offset by a decrease in the number of high types as this lowers total investigation costs.

Finally, point E in graph (c) is now located in outcome PBR on account of higher reporting costs. Increasing θ_L now does not increase investigation costs. These remain unchanged because the investigation probability necessary for deterrence remains at $\frac{c_R}{b}$ to incentivize citizens to report in line with the reporting criterion. However, low type net damages decrease and the regulator switches to UP (point F). As in the previous case, the new boundary is decreasing in θ_L because an increase in low type benefits lowering net damages can be offset by a decrease in the number of high types lowering total investigation costs.

4.3 Two impossibility corollaries

Propositions I.1 and I.2 are derived under two meaningful, but potentially limiting assumptions. The first is that the regulator combines a uniform standard with a uniform monitoring and enforcement strategy. The second assumption is that citizens are norm takers, i.e. citizens' benefits of reporting are not conditional on the agent's type. In the following we first combine a uniform standard with the possibility of tailored monitoring and enforcement to examine the implications of doing so in proposition I.3. Secondly, we extend the analysis to the case of welfare-oriented citizens. In contrast to norm-takers, these only derive a positive benefit from reporting a low type, i.e. an agent who - through his act - imposes a net loss on society.

4.3.1 Uniform standards and tailored monitoring and enforcement

The assumption of uniform standards plus uniform monitoring and enforcement may appear unduly restrictive: After all, the regulator knows each agent's type. It would therefore seem productive for the regulator to condition his monitoring and enforcement strategy on this knowledge and thus improve on the regulatory outcome. Here we show that it is not possible for the regulator to do so: Rather than improving on the efficiency of the regulatory outcome, conditioning the monitoring and enforcement strategy on type information will - at best - not improve on the outcome a uniform standard can deliver and will - at worst - reduce its benefits.

If a uniform standard does not have to be combined with a uniform monitoring and enforcement strategy, the regulator can condition the monitoring and enforcement strategy applicable to each agent on its type. Inspections, investigations, and fine levels can therefore depend on agents' types. The policies available are $\{\hat{a}, p_L, p_H, q_L, q_H, F_L, F_H\}$ as the uniform policy and $(\{1, p_L, q_L, F_L\}_L,$ $\{0, p_H, q_H, F_H\}_H)$ and $(\{0, p_L, q_L, F_L\}_L, \{1, p_H, q_H, F_H\}_H)$ as the individualized ones. The consequences of the possibility of combining uniform standards with individualized monitoring and enforcement strategies are summarized in[5]

Proposition I.3 *(Uniform standards and individualized monitoring and enforcement) If uniform standards can be combined with individualized monitoring and enforcement and citizens report agents committing acts, the equilibrium policy of the regulatory game is*
(i) $\{1, 0, 0, q_L, q_H, F_L, F_H\}$ *with* $V = n_H(\theta_H - h) - n_L(h - \theta_L)$ *if* $n_L(h - \theta_L) \leq n_L \frac{\theta_L}{w} c_{Ins}$
(ii) $\left\{0, \frac{\theta_L}{w}, q_L, w\right\}_L, \{1, 0, q_H, F_H\}_H$ *with* $V = n_H(\theta_H - h) - n_L \frac{\theta_L}{w} c_{Ins}$ *if* $n_L(h - \theta_L) > n_L \frac{\theta_L}{w} c_{Ins}$.

From a regulatory point of view, the result in proposition I.3 is rather disappointing. The setting is promising as it combines the two seemingly productive assets: On the one hand, there is the possibility of citizen reports. Properly harnessed, these reports provide the information necessary to overcome the regulator's hidden action problem. On the other hand, there is full flexibility in monitoring and enforcement for the regulator, with the expected improvements from selective targeting of enforcement.

Despite these attractive features, the outcome of this set-up collapses into a setting "without citizens": The regulator will choose a policy that induces high types to commit the act and will enforce a ban for low types if and only if net damages from low types outweigh inspection costs. The general public's monitoring ability goes unused. The reason is that at all information sets potentially on the equilibrium path where $a_i = 1$ the citizen does not report, especially at that set where the act is uniformly banned, i.e. at H_1^0. If the citizen otherwise did

[5] See the appendix for the proof.

report the regulator would exploit this behavior to enforce a ban for low types at no costs by setting $q_L F_L \geq \theta_L$. At the same time he would set a policy inducing $a_H = 1$ to realize high type net benefits. As citizens report this behavior the regulator has to carry out costly investigations with probability q_H. Contrary to the basic set-up where a uniform ban had to be combined with a uniform investigation probability, the regulator now can avoid these investigation costs by setting $q_H = 0$. This additional feature however nullifies the citizen's incentives to report as only those agents commit the act who will not be investigated and thus not be sanctioned.

The mechanism is familiar from the last section. There, however, it was operational only if the regulator sets individualized standards combined with individualized monitoring and enforcement strategies. Restricting the regulator to a combination of a uniform standard with a uniform monitoring and enforcement strategy circumvented this mechanism. Conversely, allowing the regulator to condition the response to a report on an agent's type when using uniform standards makes the mechanism reappear.

4.3.2 Welfare-concerned citizens

A similar finding arises if one assumes that citizens are not norm takers but take a welfare perspective. Citizens acting on wider welfare motives would like high types to commit the act. Therefore, a citizen receives *no benefit from reporting a high type*. Thus, welfare-concerned citizens receive benefits from reporting only if they report an agent whose act decreases welfare, i.e. low types, and if the regulator subsequently undertakes enforcement actions. The consequences if citizen reporting is driven by the welfare motive are shown in

Proposition I.4 *(Welfare-concerned citizens) If positive benefits from reporting require reporting a low type, the equilibria PBD and PBR disappear. The regulator can achieve $V = 0$ from FB only if in equilibrium the citizen reports at H_1^0.*

The intuition underpinning proposition I.4 is essentially similar to the case of combining uniform standards with tailored monitoring and enforcement, so we omit the analogous proof: As in proposition I.3, the reason is that sequential rationality no longer unequivocally requires the citizen to report at H_1^0. For the regulator to be productive a uniform ban must lead to $a_L = 0$.[6] Thus, in equilibrium only *high* types, i.e. those whom the welfare-oriented citizen does not want to report, would commit the act under a uniform ban. Therefore, if in equilibrium H_1^0 is reached with positive probability, reporting at this set is not sequential rational and low types cannot be deterred by the threat of a report. This removes the mechanism that underpins the PBD and PBR equilibria for norm-taking citizens, namely by maintaining a sufficiently high probability that the perpetrator gets punished independent of type[7].

This logic explains why welfare-oriented rather than norm-taking citizens will at best lead to the same outcome for the regulator. Welfare orientation appears to promise savings from not having to investigate high types in the PBR and PBD equilibria. Since these equilibria fail to survive under sequential rationality, so does the regulator's opportunity to achieve $a_L = 0$ and $a_H = 1$ while exploiting deterrence of citizen reports. Whether the regulator can realize $V = 0$ under the full ban (FB) depends on the citizen's equilibrium play at H_1^0. Under FB, H_1^0 is not reached and, thus, both reporting and not reporting can be sequential rational at this information set. As FB requires reporting[8] at H_1^0 the regulator cannot realize $V = 0$ if the citizen does not report at H_1^0.

[6] Otherwise the regulator would uniformly allow the act.

[7] Note that the regulator does not partially enforce a uniform ban by relying on inspections as this can be accompanied with a tailored policy.

[8] Note that a uniform ban fully enforced through inspections yields a lower V than the tailored policy with $\widehat{a}_L = 0$ and $\widehat{a}_H = 1$.

5 Discussion of part I

The previous sections set out a number of key results regarding the L.B. Jefferies problem. In passing, it should be noted that the model's results also apply to a case where citizens and agents are not randomly matched, but where there are restrictions on policy disclosure. Then, in case of tailored policies only agents of type i learn the policy for type i. Policies would not be communicated to the general public. Citizens then do not know which agent is allowed to commit the act, leading to an equivalent problem as the one studied in this paper. An agent would only know the policy he faces. The assumptions are realistic for two reasons. First, in many countries and for many activities that are regulated legal constraints prohibit agency information disclosure if the information provided contains individualized data. For instance, agency information disclosure is often not allowed if it reveals potentially valuable data to competitors. The second argument is information overload.[1] The general public can have limited cognitive abilities and therefore cannot handle an amount of information that is sufficiently large.[2] The findings in such a setting can be shown to be equivalent to the results derived here, but also include a second equilibrium that can only be eliminated through further refinements of the equilibrium concept.

Various other extensions present themselves. One is to include technical substitutes that reduce reporting cost (Grabosky 1992). However, as the unconditional benefits from reporting already exceed reporting costs for every citizen, it is clear that further initiatives to reduce the costs cannot enhance the supply of

[1]See Edmunds and Morris (2000) and Eppler and Mengis (2004) for reviews of theoretical and empirical studies on information overload in the management related literature.

[2]Actually, this argument means that the regulator could communicate tailored policies to the public. However, the consequence would be that a citizen is simply not able to find out which agent is regulated in which way because he has too much information at hand. The result would be the same as if citizens were not told the policies.

reports in the present setting. For the extension to have traction then, a model with heterogeneous citizens would be required. For example, some citizens may have greater fear of reprisal than others. Also, agents may be able to invest in raising the reporting costs of citizens. Another extension is to tie the model more closely with the harm avoidance motive that some of the literature invokes (Heyes and Kapur 2009a). In that case, the benefit b to the citizen would equal the harm h avoided as a result and the findings would go through as had. Relaxing the assumption about relationship of harm from acts to benefits from acts, a different cost-harm pattern such as $h > \theta_H > \theta_L$ can result in a reconsideration of the tenet that positive monitoring costs imply relaxing the standard (Viscusi and Zeckhauser 1979). Under given circumstances, it is trivial to show that a motivated public can help the regulator reattain the first best outcome.

6 Conclusion of part I

Going back to the starting point of the paper, we asked the question why - in a world with highly heterogeneous populations - regulators concerned about efficiency should give up the opportunity of using individualized rules. While fairness and equity reasons often serve as explanations why regulators impose uniform rules, this choice seems much harder to justify on efficiency grounds. Existing justifications emphasize both coordination benefits and reductions in the cost of regulatory design when agents' individual circumstances are costly to observe. The present paper complements these justifications by focusing instead on the monitoring and enforcement instruments that make regulations 'stick' (Heyes 1998). The resulting parsimonious and stylized model highlights a mechanism that is at once obvious and overlooked: In a world of limited monitoring and enforcement resources, regulators can obtain underappreciated benefits due to harnessing the willingness of citizens such as L.B. Jefferies to report offenders. Individualized regulations - while reducing compliance costs for the regulated - also limit the extent to which motivated citizens can feel rewarded for reporting infractions: An observed activity might be banned for one person, but allowed for another, thus detracting from the gains of doing good by reporting. Properly designed uniform standards, on the other hand, maintain the motivation to report infractions, giving rise to reduction in monitoring costs and hence to benefits for the regulator.

How profound is this insight? Clearly, it highlights the public's contribution to enforcement as a determinant of rule design, with a specific focus on the earliest stage of the monitoring and enforcement process. If at all, the literature tends to focus on its role in later stages of enforcement. This risks overlooking the important role voluntary reports to regulators play at the outset of the enforcement process. In addition, it gives rise to non-obvious regulatory policies: Uniform rules make it sequentially rational for citizens to provide costly reporting effort, but can also force the regulator to behave in a way that seems at odds with intuition. In a world in which only one of two groups is an obvious target of regulation, the regulator would be observed pursuing only the non-target group. The reason is that this pursuit maintains the supply of reporting effort, the threat of which effectively deters the target group from committing their socially undesirable activities. We show the mechanisms underpinning the results and how they are related to this and alternative information structures.

Taken together, this paper formalizes a basic point in Hitchcock (1954): Without L.B. Jefferies observing by happenstance the circumstantial evidence of a crime, a crime would have gone undetected and unretributed. But in order for L.B. Jefferies to act on his impulse of civic virtue by reporting, it is important that he has to know nothing about his anonymous neighbor in order to know that a crime has happened. The commitment of the regulator to treat everyone the same is a key to L.B. Jefferies' contribution.

Part II

Improving The Monitoring Capability of Citizen Monitoring Programs: Desirable or Not?

7 Introduction to part II

Among environmental policy researchers, the role of the citizen in environmental regulation has been undergoing something of a reconsideration in recent years. A view of citizens as passive victims of pollution has been replaced by a view of citizens as active contributors to regulatory outcomes. A growing literature focuses on understanding the ways in which citizens and environmental groups shape environmental regulation. Typical cases comprise instances of informal regulation (e.g. Kathuria 2007, Blackman 2000)[1] in which communities facing environmental threats attempt - more or less successfully - to regulate pollution in the face of weak or absent state authorities. They also include the effects of regulation through information (e.g. Cutter and Neidell 2009, Evans et al. 2009, Graff Zivin and Neidell 2009)[2]. Using contest models, Liston-Heyes (2001) and Settle et al. 2001 - among others[3] - examine settings where private parties influence regulatory decisions.

The reevaluation of the role of the citizen has been particularly palpable in the context of environmental monitoring and enforcement: From the detection of potential infractions and subsequent complaints (Dasgupta and Wheeler 1996, Eckert 2006, Weersink and Raymond 2007) to the pursuit of violators in courts (Naysnerski and Tietenberg 1992, Langpap 2007, 2008, Langpap and Shimshack 2010), decisions by citizens can influence and shape regulatory reality at all stages

[1] See also Blackman and Bannister (1998), Hartman et al. (1997), Pargal et al. (1997), Afsah et al. (1996), Pargal and Wheeler (1996), Hettige et al. (1996).

[2] See also Bennear and Olmstead (2008), Cohen and Santhakumar (2007), Goldar and Banerjee (2004), Foulon et al. (2002), Dasgupta et al. (2001), Tietenberg and Wheeler (2001), Khanna et al. (1998), Tietenberg (1998), Konar and Cohen (1997), Hamilton (1995), Kennedy et al. (1994), Magat and Viscusi (1992). Dasgupta et al. (2006) provide a survey on disclosure strategies.

[3] See also Heyes (1997), Hurley and Shogren (1997), Baik and Shogren (1994), and Park and Shogren (2003).

of the process (Tietenberg 1998, Tietenberg and Wheeler 2001). Moreover, where present, the general public's participation has often been linked to better environmental performance and improved efficiency of environmental regulation (Dasgupta et al. 2000, Escobar and Chávez 2010, Huang and Miller 2006).

Given the empirical evidence, researchers have argued that measures designed to support the general public's role in environmental regulation should be adopted more widely (Tietenberg and Wheeler 2001), in particular in the area of environmental monitoring: Given the significant resources required for an effective monitoring system, environmental lawyers (e.g. Kysar and Salzman 2008, Thompson 2000), sociologists (Forrester 1999, Overdevest and Mayer 2008, 2010) and policy institutions such as the World Bank (World Bank 2006, 1992) nowadays frequently recommend harnessing citizens to perform simple monitoring tasks whose results can serve as inputs into regulatory processes. Citizen monitoring initiatives such as 'bucket brigades' (O'Rourke and Macey 2003) are illustrative of the general idea: Members of the public collect samples in simple containers ("buckets"), carry out rudimentary analyses, and inform regulators in case of a significant finding. The idea has been practically implemented in many developing countries such as India, Philippines, and Kenya to mention just a few[4], but initiatives such as bucket brigades, 'riverkeepers', and 'baykeepers' have also evolved under U.S. EPA guidance. The EPA's National Directory of Volunteer Monitoring Programs currently lists roughly 900 organizations that monitor and assess water quality in all states and Washington, D.C. except Nevada.[5]

A well-known limitation of citizen monitoring is the extent to which citizens are able to provide an accurate picture of firms' environmental performance to regulators (e.g. Overdevest and Mayer 2010, Hunsberger et al. 2005, Savan et al 2003, O'Rourke and Macey 2003, Thompson 2000, Heiman 1997). Inaccuracies take two forms, a failure to detect and report a violation that did occur ('false negative') or, alternatively, strategically or negligently reporting a violation when,

[4]One example for an organization that aims to train and give technical assistance for using buckets to affected communities all over the world is Global Community Monitor [http://www.gcmonitor.org/].

Another organization acting for similar purposes with a focus on water pollution is the Waterkeeper Alliance [http://www.waterkeeper.org/].

[5]Source: http://yosemite.epa.gov/water/volmon.nsf/Home?openform; Last check on August 28th 2010.

in fact, no violation occurred ('false positive'). This paper is concerned with measures that reduce 'false negatives', that is improvements in citizens' capacity to detect and report pollution events. This requires members of the public taking meaningful samples at the right time and the right place, following an adequate protocol in handling and testing the sample in time, completing report forms in the correct manner, and forwarding the report in a timely manner to regulatory agencies so as to enable the latter to respond and verify sufficiently rapidly (Ottinger 2010, O'Rourke and Macey 2003). A combination of technological (standardized kits), procedural (assay protocols), and institutional safeguards (such as letters of agreement) are supposed to enhance the quality of citizen monitoring. This is easily understood: If the philosophy of citizen monitoring is to provide credible and actionable information for regulators (Kysar and Salzman 2008, Overdevest and Mayer 2008), it would seem obvious that the better citizens become at alerting regulators to pollution incidents, the greater the contribution citizens can make towards increasing environmental quality. The attempts by U.S. EPA and State authorities to foster data collection and reporting by citizen groups would seem a straightforward step towards improving regulatory outcomes. Everything else equal, greater monitoring accuracy, "better buckets" in other words, should be associated with higher welfare and lower environmental harm.

In this paper, we use a simple model to show that this logic does not necessarily hold. In fact, it is possible that in settings with enhanced citizen monitoring quality, firms comply less, harm is greater, and overall welfare is lower. Even if welfare increases overall, citizens' welfare may decrease, thus removing incentives for citizens to adopt measures that reduce false negatives. The reason for these counterintuitive results is the non-trivial interaction between the quality of monitoring, the firm's propensity to violate, and the regulator's propensity to inspect. Both firm and regulator weigh costs and benefits of their decision: For costly inspections to be worthwhile to the regulator in absence of a complaint requires a sufficient chance of finding a violation, into which the propensity to violate and error of sampling enter in an essentially substitutive manner. Likewise, for the firm to violate requires enough of a chance of 'getting away with it'. Increasing quality means, in the first instance, less of that chance, and as a result, inspections have to be disproportionately less frequent in order to violations to occur at all. In the circumstances that the paper characterizes, both effects jointly lead to higher expected harm through inducing more non-compliance. The countervailing effects of lower inspection and compliance costs may outweigh the negative welfare effects to produce overall welfare gains, but do not have to.

The spirit of the paper is not to provide a complete characterization of the interaction between the parties. Instead, we proceed by construction. The simple model on which this paper is based employs a simple three-player set-up. There is a firm that faces a dichotomous choice between costly compliance on the one hand and violation at the risk of being saddled with recovery costs upon detection on the other. The citizen suffers harm through violations that can be offset through recovery action. Citizens can take samples at a cost. The monitoring quality captures the likelihood that a pollution event is successfully detected and serves as a shorthand for the sequence of steps that needs to be completed for a pollution event to be communicated to a regulator. The regulator can inspect without a report from a citizen or investigate a report, both at a cost, and take enforcement action in form of forcing the firm to recover. We then prove the existence of a perfect Bayesian equilibrium with the mentioned properties that give rise to our results.

By examining the interaction between monitoring quality, citizen contributions to monitoring and enforcement, and regulatory outcomes, the paper contributes to the literature on citizen participation in environmental monitoring and enforcement. More specifically, by putting the key issue of monitoring quality center stage, it shares a focus with, yet is distinct from other papers examining the effects and consequences of private actors contributing to the regulatory process at the monitoring stage (Garoupa 2001, Heyes 2002, Bandyopadhyay and Chatterjee 2010). Heyes (2002) develops a theory of "filtered enforcement" in which one possible inputs into the 'filter' are noisy monitoring reports by an essentially exogenous public that can 'trigger' the enforcement stage. The present paper differs in that citizens' reports are not exogenously, but the result of an explicitly modeled decision involving a cost. Considering the cost of reporting, Garoupa (2001) examines the question of compensating citizens for reporting, but differs from our model in that the monitoring technology is perfectly accurate. Bandyopadhyay and Chatterjee (2010) study the impact of reporting ability differences between citizen groups on expected crime, but their results rely on a different mechanism implicit in the model set-up. The common concern among these papers and ours are the crowding effects and pollution outcomes of citizen activities, a concern shared with the closely related literature on citizen participation at the enforcement stage (Naysnerski and Tietenberg 1992, Heyes 1998, Heyes and Rickman 1999, Langpap 2007, Langpap and Shimshack 2010). We compare and contrast our respective results in the discussion section of this paper.

The paper proceeds as follows: We introduce the model set-up in section 8. Section 9 performs a comparative statics analysis in the neighborhood of the equilibria of interest to derive the key results and characterize the welfare impacts of different levels of accuracy on the three parties. Section 10 discusses and section 11 concludes.

8 The model of part II

8.1 Set-up

This section develops a stylized game-theoretic model of citizen monitoring programs in environmental regulation in which the effects of improving citizens' monitoring technology to detect and report pollution events can be assessed. The game involves three players: a firm taking a decision on compliance, a citizen taking a decision on monitoring, and a regulator balancing costs and benefits of enforcing regulations through costly inspections and costly investigations of citizen reports.

The timing of the game sees the firm moving first, followed by the citizen and the regulator (see figure 8.1): At the beginning the firm decides whether to comply with a pollution regulation or not. It can, for instance, run abatement equipment that avoids emitting a certain pollutant into a medium, such as a river or the air. If the firm does not pollute, it incurs compliance costs c_{com}. If it pollutes, it imposes future harm h on the citizen.

The firm's decision on whether to pollute or not is private knowledge and not observable by the citizen. However, the citizen can undertake costly activities that can bring the polluted state of the medium to the attention of the regulator. As a shorthand for the various activities that constitute the monitoring process, we assume that the citizen takes a sample with sampling cost c_{sam} and with a probability q of detecting an actual pollution event. The probability of a false negative result of the assay is $1 - q$. In the event that the assay indicates the presence of 'pollution', the citizen reports this observation to the regulator who then decides whether to investigate the incidence at cost c_{inv}. Investigations are necessary to collect judicial evidence that meets the relevant standard of proof and truthfully reveal the firm's decision. The focus on false negatives implies that the regulator can conclude from the presence of a report that the sample was taken and that the firm polluted. The regulator's information set at that point therefore contains a single node.

Both in the event of the citizen not sampling or in the event of the assay failing to detect pollution, no report is filed. In keeping with the reality of existing monitoring programs, therefore, the absence of evidence is not evidence of absence: The regulator does not know whether the firm polluted and whether the sample was not taken or whether it was taken and did not - correctly or falsely - indicate 'no pollution'. Thus, the regulator's information set where he did not receive a report contains four nodes with the respective histories (i) pollution and sample but false negative result (the regulator's belief that this is the prior play of the game is μ_1), (ii) pollution and no sample (μ_2), (iii) no pollution and no sample (μ_3), and (iv) no pollution and sample with a correct negative result (μ_4). In either case the regulator decides whether to monitor on his own using inspections. These cost c_{ins} and truthfully reveal whether the firm polluted. Investigations or inspections establishing pollution imply that the firm is forced to recover.[1] Recovery eliminates harm at costs $c_{rec} > c_{com}$ for the firm and constitutes the final stage of the game.

In an alternative timing the regulator would decide whether to inspect before the citizen makes his sampling decision. We analyze the other case because citizens typically are closer to potential polluters. They receive a signal about pollution, e.g. bucket brigades' sniffers who recognize malodor, and can react quickly on pollution evidence. In fact, one of the main purposes of citizen monitoring is to provide an alert function that allows the regulator to quickly respond to pollution incidents. This naturally requires that citizens act before the regulator comes into play.

We now turn to the strategy sets and payoffs of the three players. Consider first the players' strategies. The firm's strategy of compliance is given by the probability with which the firm pollutes and denoted by $\alpha \in [0, 1]$. Analogously,

[1] For simplicity we do not assume that the firm also has to pay a fine in case of pollution. A fine would increase the firm's negative payoff after investigations or inspections. However, as will become clear below, introducing such a fine will not alter the results qualitatively. It would only change the equilibrium choices quantitatively.

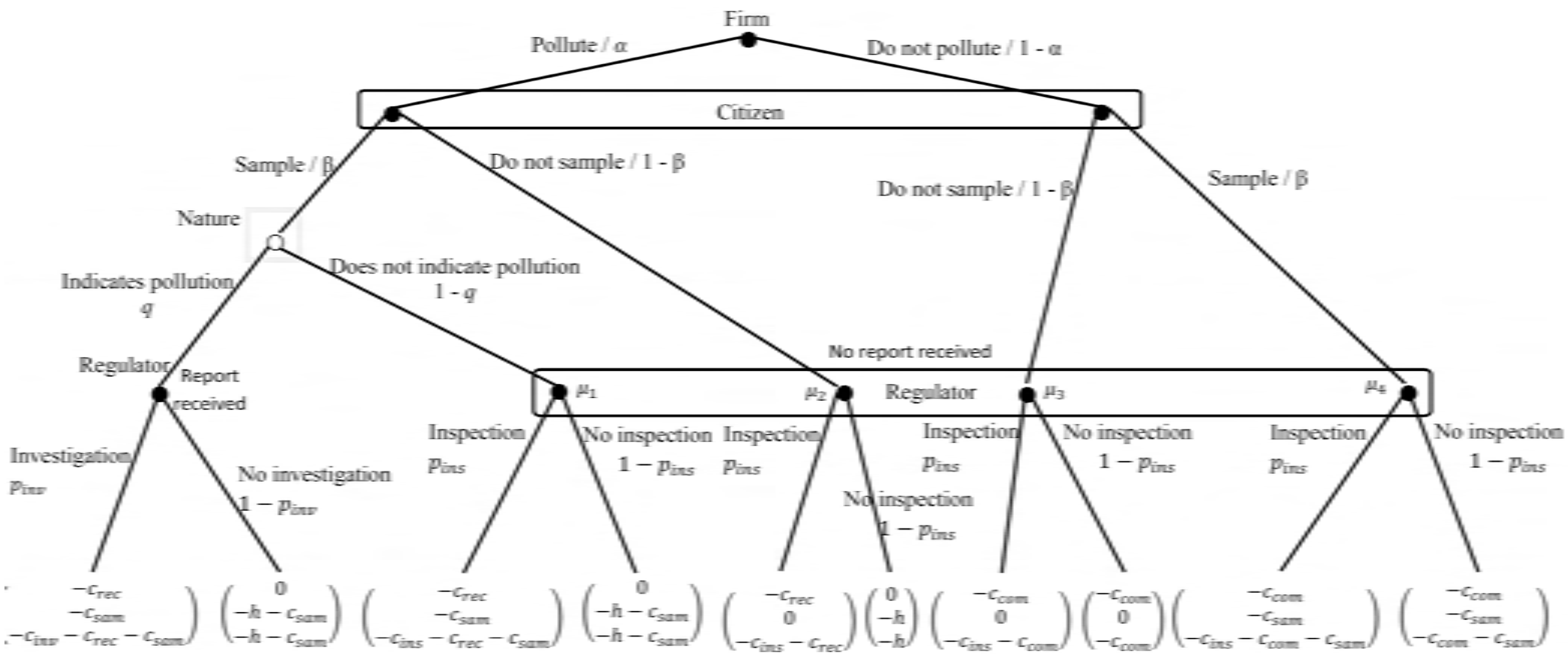

Figure 8.1: The Game Tree.

the citizen's probability of taking the sample is denoted by $\beta \in [0,1]$ and, finally, the regulator's probability of investigations and inspections by $p_{inv} \in [0,1]$ and $p_{ins} \in [0,1]$, respectively. Secondly, the expected payoff u for the citizen is

$$u = -\alpha \left\{ (1-\beta)(1-p_{ins}) + \beta \left[q(1-p_{inv}) + (1-q)(1-p_{ins}) \right] \right\} h - \beta c_{sam}. \tag{II.1}$$

The citizen suffers future harm h if the firm pollutes (α) and the regulator undertakes no enforcement actions. This arises in three circumstances: (1) The citizen does not take the sample and the regulator does not inspect ($(1-\beta)(1-p_{ins})$), (2) the sample is taken but the regulator does not investigate in case of a report ($\beta q(1-p_{inv})$), or (3) the regulator does not inspect in case of a false negative result ($\beta(1-q)(1-p_{ins})$). Additionally, the citizen incurs sampling costs whenever he takes the sample.

The expected payoff π for the firm is

$$\pi = -\alpha \left\{ (1-\beta) p_{ins} + \beta \left[q p_{inv} + (1-q) p_{ins} \right] \right\} c_{rec} - (1-\alpha) c_{com}.$$

The firm has to pay for recovery whenever it pollutes and the regulator subsequently undertakes enforcement actions. Thus, in case of pollution (α) it has to pay for recovery in three circumstances: (1) The citizen does not take the sample but the regulator inspects ($(1-\beta) p_{ins}$), (2) the citizen takes the sample and the regulator investigates in case of a correct positive sample ($\beta q p_{inv}$), and finally (3) the regulator inspects in case of a false negative sample ($\beta(1-q) p_{ins}$). Additionally, if the firm does not pollute $(1-\alpha)$ it incurs compliance costs.

For the regulator we presume a welfare approach: He takes the firm's and the citizen's payoffs as well as inspection and investigation costs into account. The regulator's expected payoff W is then

$$\begin{aligned} W &= -\alpha \left\{ \begin{array}{c} \beta \left[\begin{array}{c} q\left(p_{inv}\left(c_{inv}+c_{rec}\right)+\left(1-p_{inv}\right)h\right)+ \\ \left(1-q\right)\left(p_{ins}\left(c_{ins}+c_{rec}\right)+\left(1-p_{ins}\right)h\right) \end{array} \right] \\ +\left(1-\beta\right)\left[p_{ins}\left(c_{ins}+c_{rec}\right)+\left(1-p_{ins}\right)h\right] \end{array} \right\} \\ &\quad -(1-\alpha) p_{ins} c_{ins} - (1-\alpha) c_{com} - \beta c_{sam}. \end{aligned} \tag{II.2}$$

If the firm pollutes (α) the regulator incurs enforcement and recovery costs in three circumstances: (1) The sample is taken and the regulator investigates $(\beta q p_{inv})$, (2) the sample taken is a false negative and the regulator inspects $(\beta(1-q)\,p_{ins})$, and (3) the sample is not taken and the regulator inspects $((1-\beta)\,p_{ins})$. If no enforcement actions are carried out $(\beta q(1-p_{inv}) + \beta(1-q)(1-p_{ins}) + (1-\beta)(1-p_{ins}))$, welfare W is decreased by harm. If instead the firm does not pollute $(1-\alpha)$, the regulator incurs inspection costs if he inspects and welfare is decreased by compliance costs. If the sample is taken, welfare decreases on account of sampling costs. From the regulator's welfare perspective, a necessary condition for undertaking enforcement actions at all is that harm exceeds recovery and enforcement costs, i.e. $h > c_{rec} + \max\{c_{ins}, c_{inv}\}$. Having described the structure of the regulatory game we now derive the equilibria.

8.2 Regulatory equilibria

Depending on the precise parameters, the game need not feature a unique equilibrium. Since the purpose of the paper is to examine the comparative statics of improving monitoring quality, we do not provide a detailed analysis of all possible equilibria or discuss issues of equilibrium selection. Instead, we focus on two salient equilibria: The first is a 'full sampling equilibrium' where the citizen plays the degenerate strategy $\beta = 1$. This reflects a situation where citizens take air or water samples, for instance, on a daily basis. This is an extreme scenario, but nevertheless it can naturally arise in circumstances when the environmental or health threat on community members is substantial. Potential releases of heavy metals and carcinogenic substances serve as illustrative examples. The second equilibrium is a 'no inspection equilibrium' where the citizen follows a mixed strategy, i.e. $0 < \beta < 1$. The following analysis shows that a low error probability in citizen sampling is a necessary condition for the 'no inspection equilibrium' to occur. Therefore, this scenario points to (a future) situation where citizen sampling has become sufficiently accurate so that optimal deterrence might be solely maintained by private monitoring.

The following contains existence proofs for each of the two equilibria. The equilibrium concept is perfect Bayesian equilibrium (PBE), with equilibrium choices denoted by an asterisk.

8.2.1 Full sampling equilibrium

The full sampling equilibrium features $\beta = 1$. For this to be part of an equilibrium, the probability of accurately detecting pollution through sampling has to be sufficiently small, i.e. $q < \frac{c_{com}}{c_{rec}}$, as will be shown below. Put differently, the error probability must be sufficiently large.

To derive the equilibrium, consider first the single-node information set where the regulator received a report. Sequential rationality requires that he investigates the report with probability one. Thus, $p^*_{inv} = 1$. The reason is that the assay indicates pollution only if the firm did indeed pollute. Therefore, the regulator - as well as the citizen - knows that a positive sample can only follow pollution. In that case there is no uncertainty.

Things are different if the regulator did not receive a report. The decision whether to inspect is then one under uncertainty and the regulator has to form beliefs about the prior play of the game. This belief is the key in understanding the central results of this paper. If the regulator did not receive a report he does not know whether the firm polluted and whether the sample was not taken or whether it was taken and showed a correct or false negative result. Note first, that in the equilibrium with $\beta = 1$ the regulator's equilibrium belief that in case of no report the sample was not taken is zero (i.e. $\mu_2 + \mu_3 = 0$) and we do only have to consider the two nodes where the citizen sampled. In the full sampling equilibrium the regulator's equilibrium belief that the firm polluted but the taken sample falsely indicated 'no pollution' μ_1, i.e. $\mu_1 = \Pr(\text{pollution but false neg. sample} \mid \text{no report})$, is relevant. Second, we derive this μ_1 as a solution to the regulator's *inspection condition*: For a given μ_1 and μ_4 with $\mu_4 = 1 - \mu_1$ the regulator will inspect if and only if the expected payoff from inspections is larger than from not inspecting, i.e.

$$-\mu_1 c_{rec} - (1 - \mu_1)\, c_{com} - c_{ins} - c_{sam} \geq -\mu_1 h - (1 - \mu_1)\, c_{com} - c_{sam} \tag{II.3}$$

or equivalently if his belief that he received no report although the firm polluted is sufficiently large:

$$\mu_1 \geq \frac{c_{ins}}{h - c_{rec}}. \tag{II.4}$$

Because $0 < \frac{c_{ins}}{h-c_{rec}} < 1$,[2] (II.4) has to hold with equality: Suppose $\mu_1 > \frac{c_{ins}}{h-c_{rec}}$. The regulator then would set $p_{ins} = 1$. The expected payoff for the firm from polluting would be $-c_{rec} < -c_{com}$ and it would choose $\alpha = 0$. But then $\mu_1 = 0$ - a contradiction. Assume instead $\mu_1 < \frac{c_{ins}}{h-c_{rec}}$. The regulator would not inspect, so $p_{ins} = 0$, yielding the payoff $-qc_{rec}$ for the firm if it pollutes which is larger than $-c_{com}$ because by assumption $q < \frac{c_{com}}{c_{rec}}$. But then for the firm polluting is strictly better than complying and so $\alpha = 1$. However, then $\mu_1 = 1$ - again a contradiction. Therefore, in equilibrium (II.4) holds with equality. In a perfect Bayesian equilibrium beliefs are derived through Bayes' rule given the other players' equilibrium strategies. Thus, the regulator derives his equilibrium belief according to

$$\mu_1 = \frac{\alpha^* (1-q)}{\alpha^* (1-q) + (1-\alpha^*)} = \frac{\alpha^* (1-q)}{1-\alpha^* q}. \tag{II.5}$$

This must equal the right hand side in (II.4), so that

$$\mu_1 = \frac{\alpha^* (1-q)}{1-\alpha^* q} = \frac{c_{ins}}{h-c_{rec}}. \tag{II.6}$$

This expression determines the firm's equilibrium strategy which makes the regulator indifferent between inspecting and not inspecting if he receives no report:

$$\alpha^* = \frac{c_{ins}}{(1-q)(h-c_{ins}-c_{rec}) + c_{ins}}. \tag{II.7}$$

In equilibrium the firm's strategy must be such that the regulator's belief μ_1 equalizes the expected payoff from inspecting and not inspecting respectively. According to (II.6) this belief is sensitive to changes in the model's parameters:[3] Increases in inspection or recovery costs make inspections c.p. relatively less attractive and require a higher μ_1 - a higher chance of detecting a violation during inspections - for the regulator to inspect with a positive probability. Thus, the firm's equilibrium strategy must increase.[4] Conversely, an increase in harm renders inspections relatively more attractive. To counteract this effect, α^* has to

[2] The second inequality holds because by assumption $h > c_{rec} + \max\{c_{ins}, c_{inv}\}$.

[3] The analysis of changes in the citizen's monitoring accuracy, i.e. q, is delegated to the next section.

[4] Note that according to (II.7) we get $\frac{\partial \alpha^*}{\partial c_{ins}}, \frac{\partial \alpha^*}{\partial c_{rec}} > 0$.

decrease so that the regulator's chance of finding a violation during inspections decreases.[5]

Having described the firm's equilibrium strategy we now determine the equilibrium inspection probability p^*_{ins}. Consider the firm's *compliance condition*: The firm will comply if and only if[6]

$$-\left[q+(1-q)\,p_{ins}\right]c_{rec}\leq -c_{com}. \tag{II.8}$$

This expression has to hold with equality: If the left hand side is larger we would get $\alpha = 1$ which according to (II.5) leads to $\mu_1 = 1$ contradicting $\mu_1 < 1$. If instead the left hand side is smaller the firm chooses $\alpha = 0$ which yields $\mu_1 = 0$ contradicting $\mu_1 > 0$. So the equilibrium inspection probability is[7]

$$p^*_{ins}=\frac{1}{1-q}\left[\frac{c_{com}}{c_{rec}}-q\right]=\frac{c_{com}-qc_{rec}}{(1-q)\,c_{rec}}. \tag{II.9}$$

The regulator's inspection probability must make the firm indifferent between polluting and not polluting. Similar to the case of α^* the inspection probability is sensitive to changes in the parameters: An increase in compliance costs makes polluting c.p. relatively more attractive for the firm. To counteract this effect the equilibrium inspection probability has to increase to raise expected recovery costs. Conversely, an increase in recovery costs makes polluting c.p. relatively less attractive so that in equilibrium inspections have to be carried out less frequently.

Finally, in equilibrium $\beta = 1$ must be a best response for the citizen. This is the case whenever the expected benefit of sampling, relative to not, exceeds the sampling costs. The citizen's *sampling condition* is satisfied whenever the harm additionally avoided due to taking the sample exceeds sampling costs, i.e. whenever

$$\alpha^*\left(1-p^*_{ins}\right)h-\alpha^*\left(1-q\right)\left(1-p^*_{ins}\right)h\geq c_{sam} \tag{II.10}$$

[5]This is because $\frac{\partial\alpha^*}{\partial h}<0$.

[6]This expression already takes $p^*_{inv}=1$ into account.

[7]This expression shows that $q<\frac{c_{com}}{c_{rec}}$ is necessary for the existence of an equilibrium with $\beta=1$.

or equivalently

$$\frac{qc_{ins}\left(c_{rec}-c_{com}\right)h}{\left[\left(1-q\right)\left(h-c_{ins}-c_{rec}\right)+c_{ins}\right]\left(1-q\right)c_{rec}}\geq c_{sam} \tag{II.11}$$

holds. Changes in the parameters affect the citizen's incentive to sample: First, an increase in inspection costs c_{ins} increases the harm additionally avoided because higher inspection costs are accompanied by a higher α^* leading to more pollution. Second, higher recovery costs c_{rec} likewise increase the harm additionally avoided due to two effects. On the one hand, an increase in recovery costs yields a higher α^*, and on the other hand it decreases the equilibrium inspection probability p^*_{ins}. The former effect leads to more pollution whereas the latter implies *c.p.* less recovery after inspections. Third, higher compliance costs c_{com} mean a decrease in harm avoided from sampling because higher compliance costs are accompanied by a higher inspection probability, which implies more recovery in the absence of sampling. Fourth, an increase in harm h has two counteracting effects. On the one hand more harm directly affects the citizen negatively but on the other hand higher harm leads to a lower probability of pollution α^*. Taken together an increase in harm has an ambiguous effect on the citizen's incentive to sample.[8]

Before we prove the existence of the 'no inspection equilibrium' we briefly summarize the results derived so far. If $h > c_{rec} + \max\{c_{ins}, c_{inv}\}$, $q < \frac{c_{com}}{c_{rec}}$ and (II.11) holds, then the regulatory game features a perfect Bayesian equilibrium in which the citizen samples with probability one ('full sampling equilibrium') and the regulator investigates every report. The regulator's belief that the taken sample falsely indicated 'no pollution' in case of no report must be such that he is indifferent between inspecting and not inspecting. This μ_1 is the right hand side in (II.6). The firm's equilibrium strategy that yields this belief and thus makes the regulator indifferent at the information set where he received no report is that in (II.7). Finally, the inspection probability that makes the firm indifferent between polluting and not polluting is that in (II.9).

[8]Formally, these results are derived by differentiating (II.10) w.r.t. to the respective parameters: The left hand side in (II.10) can be written as $\alpha^*\left(1-p^*_{ins}\right)hq$. Thus, the changes are first $\underbrace{\frac{\partial\alpha^*}{\partial c_{ins}}}_{>0}\left(1-p^*_{ins}\right)hq>0$, second $\underbrace{\frac{\partial\alpha^*}{\partial c_{rec}}}_{>0}\left(1-p^*_{ins}\right)hq-\alpha^*\underbrace{\frac{\partial p^*_{ins}}{\partial c_{rec}}}_{<0}hq>0$, third $-\alpha^*\underbrace{\frac{\partial p^*_{ins}}{\partial c_{com}}}_{>0}hq<0$ and fourth $\underbrace{\frac{\partial\alpha^*}{\partial h}}_{<0}\left(1-p^*_{ins}\right)hq+\alpha^*\left(1-p^*_{ins}\right)q\lesseqgtr 0$.

8.2.2 No inspection equilibrium

The other salient equilibrium of the game is the 'no inspection equilibrium'. This equilibrium does not require $\beta = 1$ and so μ_2 and μ_3 can be greater than zero. Like in the 'full sampling equilibrium', sequential rationality requires the regulator to investigate every report, i.e. $p^*_{inv} = 1$.

Analogously to the *inspection condition* (II.3), the *no inspection condition* is

$$-\mu_1 \left(c_{rec} + c_{sam}\right) - \mu_2 c_{rec} - \mu_3 c_{com} - \mu_4 \left(c_{com} + c_{sam}\right) - c_{ins} <$$
$$-\mu_1 \left(h + c_{sam}\right) - \mu_2 h - \mu_3 c_{com} - \mu_4 \left(c_{com} + c_{sam}\right)$$

or equivalently[9]

$$\mu_1 + \mu_2 < \frac{c_{ins}}{h - c_{rec}}. \tag{II.12}$$

The regulator will not inspect if and only if this condition is satisfied. Thus given that (II.12) holds, the regulator's equilibrium inspection probability is $p^*_{ins} = 0$. Below we state the parameter restriction that ensures (II.12) is met.

Consider now the firm's *compliance condition* along the lines of (II.8): The firm complies if and only if

$$-\beta^* q c_{rec} \leq -c_{com}. \tag{II.13}$$

In equilibrium this has to hold with equality: If $-\beta^* q c_{rec} < -c_{com}$ complying yields a strictly greater payoff than polluting and so $\alpha = 0$. But then the citizen's best response is to never sample, i.e. $\beta = 0$ violating $-\beta^* q c_{rec} < -c_{com}$. If instead $-\beta^* q c_{rec} > -c_{com}$ polluting is strictly better than complying, so $\alpha = 1$ which implies $\mu_1 + \mu_2 = 1$, violating (II.12).

Because (II.13) holds with equality the citizen's equilibrium strategy is

$$\beta^* = \frac{c_{com}}{q c_{rec}} \tag{II.14}$$

This is the citizen's mixed strategy that makes the firm indifferent between com-

[9] In fact, one can show that in no equilibrium $\mu_1 + \mu_2 > \frac{c_{ins}}{h - c_{rec}}$ is possible. The case $0 < \beta < 1$ and $\mu_1 + \mu_2 = \frac{c_{ins}}{h - c_{rec}}$ is possible but yields a non-tracktable equilibrium that does not lead to deeper insights for the point important in this paper.

plying and polluting. The equilibrium sampling probability shows that the 'no inspection equilibrium' can exist only if the probability of a correct positive result q is sufficiently large, or if the error probability is sufficiently small: The right-hand side of (II.14) is smaller unity if and only if $q > \frac{c_{com}}{c_{rec}}$. Therefore, for a given quality level q, the two equilibria of 'no inspection' and 'full sampling' are mutually exclusive.

The firm's equilibrium probability of pollution α^* results from the citizen's *sampling condition* that is the analog to (II.10). The citizen will sample if and only if

$$\alpha^* h - \alpha^* (1-q) h \geq c_{sam}$$

or

$$\alpha^* \geq \frac{c_{sam}}{qh} \tag{II.15}$$

which has to hold with equality: If $\alpha < \frac{c_{sam}}{qh}$ ($\alpha > \frac{c_{sam}}{qh}$) we would get $\beta = 0$ ($\beta = 1$) violating (II.14). Thus, the equilibrium pollution probability is

$$\alpha^* = \frac{c_{sam}}{qh}. \tag{II.16}$$

It remains to show under which condition the regulator indeed does not inspect if he receives no report. According to Bayes' rule we get $\mu_1 = \frac{\alpha^*\beta^*(1-q)}{1-\alpha^*\beta^* q}$ and $\mu_2 = \frac{\alpha^*(1-\beta^*)}{1-\alpha^*\beta^* q}$. Substituting this into (II.12) yields

$$\frac{\frac{c_{sam}}{qh}\left(1 - \frac{c_{com}}{qc_{rec}} q\right)}{1 - \frac{c_{sam}}{qh}\frac{c_{com}}{qc_{rec}} q} < \frac{c_{ins}}{h - c_{rec}}$$

and so not inspecting is a best response if and only if inspections are sufficiently costly in the sense that

$$\frac{c_{sam}\left(c_{rec} - c_{com}\right)}{qhc_{rec} - c_{sam}c_{com}}\left(h - c_{rec}\right) < c_{ins}. \tag{II.17}$$

To summarize, if $q > \frac{c_{com}}{c_{rec}}$ and if (II.17) holds the regulatory game features a 'no inspection equilibrium' where $p^*_{ins} = 0$, $p^*_{inv} = 1$, $\alpha^* = \frac{c_{sam}}{qh}$, $\beta^* = \frac{c_{com}}{qc_{rec}}$ together with the resulting system of beliefs.

9 Comparative analysis of monitoring quality

The preceding analysis allows us to study the impact of improvements in monitoring quality on the regulatory equilibrium. The improvement in monitoring quality stems from a technological innovation. In principle innovations can lead to higher quality, lower costs or a combination of both. In this paper we consider innovations that exclusively bring about a higher sampling accuracy instead of savings in sampling costs. In keeping with the model, differences in monitoring quality then mean a better sampling technology with a reduced error probability $(1-q)$ while keeping c_{sam} constant.

The comparative statics first consider how changes in q affect payoffs in the 'no inspection equilibrium'. In this case, the "natural" intuition that employing a better technology yields a superior outcome will hold true. We then study the impacts of changes in q in the 'full sampling equilibrium'. In this case, the "natural" intuition fails: Better technologies can lead to more harm and to a decrease in welfare. We discuss this case in detail. The results are derived by considering marginal changes in q so that $q < \frac{c_{com}}{c_{rec}}$ and $q > \frac{c_{com}}{c_{rec}}$, respectively, hold. For ease of comparability, we assume that a marginal change in q does not alter the nature of the equilibrium.

9.1 No inspection equilibrium

9.1.1 Equilibrium strategies

In this equilibrium the regulator's choices are not affected by changes in q. As in (II.14) the citizen's equilibrium strategy is $\beta^* = \frac{c_{com}}{qc_{rec}}$ which is decreasing in q. The reason is that in equilibrium the citizen's frequency of sampling serves to make the firm indifferent between polluting and complying. An increase in q, however, yields in expectation more reports and thus more investigations and so higher expected recovery costs for the firm. Because the regulator's policy does not change this effect has to be offset by a decrease in β^*. A decrease in the sampling probability leads c.p. to a decrease in expected recovery costs. In total the probability for the firm that it has to recover after pollution has to stay constant. This is indeed the case because this probability is $\beta^* q = \frac{c_{com}}{qc_{rec}} q = \frac{c_{com}}{c_{rec}}$ which does not depend on q. The firm's equilibrium strategy decreases as well. The polluting probability has to make the citizen indifferent. His benefit from sampling is the harm he (additionally) avoids which is $\alpha^* qh$. An increase in sampling accuracy increases the harm avoided and because sampling costs do not change the increase in the citizen's expected benefit has to be offset by a decrease in the polluting probability.[1]

9.1.2 Equilibrium payoffs

Having described the changes in the 'no inspection equilibrium' strategies we now analyze the changes in the equilibrium payoffs. Consider first, the firm's payoff. This does not change because the firm has to be indifferent between polluting and complying. As complying yields $-c_{com}$ this also holds in expectation if it pollutes with a positive probability independent of q. Second, the citizen's payoff increases because expected harm decreases. This is $\alpha^* (1 - \beta^*) h + \alpha^* \beta^* (1 - q) h$. Substituting (II.16) and (II.14) and rearranging terms shows that expected harm is $\frac{c_{sam}}{q} \left(1 - \frac{c_{com}}{c_{rec}}\right)$ which is decreasing in q. This shows that in the 'no inspection equilibrium' a better monitoring technology is associated with improved environmental quality. Third, overall welfare increases: Substituting $p_{ins}^* = 0$, $p_{inv}^* = 1$,

[1] Formally, (II.16) gives us $\frac{\partial \alpha^*}{\partial q} = -\frac{c_{sam}}{hq^2} < 0$.

(II.16) and (II.14) in (II.2) yields $W = -\frac{c_{sam}}{q}\left(1 + \frac{c_{inv}c_{com}}{hc_{rec}}\right) - c_{com}$ which is increasing in q.

9.2 Full sampling equilibrium

The comparative analysis for the 'no inspection equilibrium' shows that improving monitoring technologies can be desirable. In the following we show that this does not necessarily hold.

9.2.1 Equilibrium strategies

Consider first the firm's equilibrium strategy as stated in (II.7). The probability that the firm pollutes increases in q because

$$\frac{\partial \alpha^*}{\partial q} = \frac{c_{ins}\left(h - c_{ins} - c_{rec}\right)}{\left[\left(1-q\right)\left(h - c_{ins} - c_{rec}\right) + c_{ins}\right]^2} > 0.$$

If citizens employ a better monitoring technology and hence the probability that the firm has to recover after investigations increases[2] the probability that the firm pollutes increases as well. The reason for this counterintuitive result originates from the regulator's equilibrium belief. Suppose that the firm's equilibrium strategy did not change. Then the regulator's equilibrium belief that he received no report due to a false negative result, i.e. μ_1, which is derived from the firm's strategy is decreasing in q because $\left(\partial\frac{\alpha^*(1-q)}{1-\alpha^* q}\right)/\partial q = \frac{-(1-\alpha^*)\alpha^*}{(1-\alpha^* q)^2} < 0$. For any pollution probability the probability that the assay shows a false negative result decreases and thus the regulator adjusts his belief that this is the reason why he received no report downwards. But in equilibrium (II.4) has to hold with equality and μ_1 is a constant independent of q. To offset the decrease in $\frac{\alpha^*(1-q)}{1-\alpha^* q}$ due to the increase in q the probability of pollution has to increase as $\partial\left(\frac{\alpha^*(1-q)}{1-\alpha^* q}\right)/\partial \alpha^* = \frac{1-q}{(1-\alpha^* q)^2} > 0$.

Second, consider the change in the inspection probability. For the firm to have an incentive to increase α, the probability of recovery after inspections has to decrease because the firm faces higher expected recovery costs after investigations

[2]Obviously the equilibrium probability of investigations p^*_{inv} remains unchanged.

due to a higher q. This is indeed the case because $(1-q)$ and the inspection probability decrease:

$$\frac{\partial p_{ins}^*}{\partial q} = \frac{c_{com} - c_{rec}}{(1-q)^2 \, c_{rec}} < 0.$$

From the firm's point of view the change in p_{ins}^* or rather in $(1-q)\, p_{ins}^*$ is of minor importance. The relevant dimension is the probability of recovery after pollution. As the equilibrium investigation probability is one, the probability of recovery if the assay indicates 'pollution' increases by the same amount q increases. Now, because $\frac{\partial\left((1-q)p_{ins}^*\right)}{\partial q} = -1$ the probability of recovery if the assay indicates 'no pollution' decreases by the amount q increases and thus exactly offsets the first effect. The reason is the following: Suppose that the increase in q exceeds the decrease in $(1-q)\, p_{ins}^*$. Then, starting from a situation where the firm is indifferent between pollution and no pollution, the increase in expected recovery costs would render not to pollute the unique best response for the firm. But then $p_{ins}^* > 0$ would no longer be a best response for the regulator contradicting (II.9) which requires $0 < p_{ins}^* < 1$. Contrary, if the increase in q is smaller than the decrease in $(1-q)\, p_{ins}^*$ the firm's unique best response would become $\alpha = 1$ making $p_{ins}^* = 1$ a best response for the regulator which again contradicts (II.9). So, to remain in equilibrium the probability of recovery after inspections $(1-q)\, p_{ins}^*$ has to decrease by the same amount as the probability of recovery after investigations q increases. Only in that case the regulator and the firm will still choose an interior solution. Further, this result shows that the use of a better monitoring technology allows the regulator to substitute inspections by investigations to provide deterrence. However, without further restrictions on the parameters, i.e. on inspection and investigation costs, nothing can be said about the cost effectiveness of this effect.

9.2.2 Equilibrium payoffs

Having considered the changes in the equilibrium strategies we now turn to the analysis of changes in the equilibrium payoffs that accrue if the employed monitoring technology improves.

The firm's payoff The firm's equilibrium payoff does not change if q increases. The reason is that the firm chooses an interior pollution probability. This requires that it is indifferent between the two strategies available. Because the firm gets a payoff of $-c_{com}$ if it does not pollute independent of the other players' strategies this must also be the equilibrium payoff independent of q.

The regulator's payoff The expression in (II.2) shows that the regulator's payoff involves six components: investigation costs, inspection costs, harm, recovery costs, compliance costs and sampling costs - each in its respective expected value. Except sampling costs, which are constant, we consider these components separately. The results are summarized in[3]

Proposition II.1 *Increasing the accuracy of citizen monitoring in the full sampling equilibrium leads to*

1. *higher expected investigation costs,*
2. *lower expected inspection costs,*
3. *higher expected harm,*
4. *higher expected recovery costs, and*
5. *lower expected compliance costs.*

First, the proposition shows that expected investigation costs increase. Expected investigation costs are $\alpha^* q p_{inv}^* c_{inv}$, i.e. investigations are carried out whenever the firm polluted and the assay indeed indicated pollution. Therefore, because the investigation probability remains one, expected investigation costs are positively affected by two effects. The first is due to the increase in the pollution probability α^* and the second stems from the higher probability of a correct positive result q.

Second, expected inspection costs decrease. They are $(1 - \alpha^* q)\, p_{ins}^* c_{ins}$ and are carried out whenever the sample does not indicate pollution. It does not indicate pollution in two situations. One where the firm does not pollute and the

[3]The formal proof is straightforward and thus omitted.

other where the firm pollutes but the assay indicates no pollution. The probability that one of the two situations occurs is $1 - \alpha^* q$. As both α^* and q increase this probability decreases. Further, the equilibrium inspection probability p^*_{ins} gets smaller as well. Thus, the probability that the regulator carries out inspections decreases and so do expected inspection costs.

Third - and most remarkable - expected harm increases. The previous section already demonstrated that a lower error probability leads to more pollution. However, the relevant factor is not pollution but harm, or more precisely the harm that is not recovered after pollution. An increase in the probability of pollution would not worsen environmental quality if the additive pollution would get recovered or the firm would even have to recover more than the additional pollution. Nonetheless, in the set-up considered here this is not the case. Here, a better monitoring technology unambiguously leads to more expected harm. Expected harm is $\alpha^* (1-q)(1-p^*_{ins})\, h$ and occurs whenever the firm pollutes but is not forced to recover. Because recovery is always ruled if the assay shows a positive result the only situation where recovery is not ruled is whenever the firm pollutes, the assay shows a false negative result and the regulator does not inspect. Rewriting expected harm yields $\alpha^* \{(1-q) - (1-q)\, p^*_{ins}\}\, h$. Differentiating this w.r.t. q yields

$$\frac{\partial \alpha^*}{\partial q} \{(1-q) - (1-q)\, p^*_{ins}\}\, h + \alpha^* \left[-\frac{\partial q}{\partial q} - \underbrace{\frac{\partial \left[(1-q)\, p^*_{ins}\right]}{\partial q}}_{=-1} \right] h =$$
$$\frac{\partial \alpha^*}{\partial q} \{(1-q) - (1-q)\, p^*_{ins}\}\, h > 0.$$

This shows that a change in q affects expected harm in two respects. The first is the effect of the pollution probability α^* which increases. The second effect is due to the changes in the probability that the firm is not forced to recover. This is the case whenever the assay does not indicate pollution (with probability $1-q$) except when the regulator inspects conditional that no pollution was indicated (with probability $(1-q)\, p^*_{ins}$). The probability that the assay falsely indicates no pollution decreases which c.p. leads proportionally to more recovery.

However, the effect on the conditional probability $(1-q)\,p^*_{ins}$ counteracts the former. Now, because $\partial\left[(1-q)\,p^*_{ins}\right]/\partial q = -1$ the latter effect exactly offsets the former.[4] Therefore, the only effect that remains active is the change in the pollution probability which increases. Although the probability that pollution gets recovered remains unchanged expected harm increases becauses the probability of pollution increases.

Fourth, expected recovery costs increase. Recall that expected recovery costs are given by $\alpha^*\left[q+(1-q)\,p^*_{ins}\right]c_{rec}$, so the firm incurs recovery costs whenever it pollutes and either the assay indicates pollution or if the assay indicates no pollution but the regulator inspects. Expected recovery costs are affected by the increase in the probability of pollution and by the change in the probability of enforcement actions if the firm polluted. The first effect leads c.p. to an increase in expected recovery costs. As previously shown the probability of enforcement actions remains unchanged so that in total expected recovery costs increase.

Fifth, expected compliance costs decrease. This must hold because the firm's equilibrium payoff does not change if q changes and as expected recovery costs increase the other payoff component has to decrease in its expected value. Expected compliance costs are $(1-\alpha^*)\,c_{com}$ and as α^* increases the probability of compliance decreases.

The citizen's payoff The citizen's equilibrium payoff decreases. It is affected by expected harm and sampling costs and is $-\alpha^*(1-q)(1-p^*_{ins})\,h - c_{sam}$. As the proposition shows, expected harm increases. Therefore, as sampling costs are constant the citizen has a lower payoff in the new equilibrium.

[4] See the previous section for the reason why the second effect exactly offsets the first.

10 Discussion of part II

The key result of the paper is that an increased probability that citizen monitoring will successfully detect pollution is not necessarily associated with lower pollution, higher welfare overall, and higher welfare for citizens. The result calls for a careful assessment of the strategic situation in which firms, citizens, and regulators operate before advocating ostensibly sensible, but possibly problematic policy advice. In the following, we first identify how this result adds to the current body of knowledge. We then discuss the potential consequences of relaxing a few of the model's assumptions to understand more about the robustness of the findings.

10.1 Contribution to the existing literature

As the introduction makes clear, the literature on private inputs into regulatory monitoring and enforcement processes considers similar questions as the present paper. It is natural, therefore, that there are important similarities, but also important differences between the present paper and previous work on citizen participation at the monitoring stage and on citizen participation at the enforcement stage.

Papers on private participation at the enforcement stage obviously examine a different step in the overall process, but contain comparable results: Theoretically, Heyes and Rickman (1999), Langpap (2007), and Heyes (1998) show that private enforcement can have crowding effects on regulatory monitoring and enforcement. Empirically, the early analysis by Naysnerski and Tietenberg (1992) suggests that private and public enforcement are inversely related. The study conducted by Langpap and Shimshack (2010) finds that private enforcement leads to a crowding-in of regulatory monitoring whereas it crowds-out regulatory sanctioning.

Previous work on private participation at the monitoring stage contains results of a comparable nature, but differs in modeling assumptions and mechanisms. Heyes' (2002) theory of "filtered enforcement" analyzes a two-stage process of emissions monitoring and enforcement, with a noisy first stage signal of the appropriate strength triggering enforcement. The first-stage signal can be interpreted as citizens' propensity to report. Heyes shows that a better signal has a qualitatively ambiguous effect on overall emissions because a better signal can lower the probability of second stage enforcement. Despite the superficial similarity, the mechanisms at work differ between the two papers. First, if the trigger is interpreted as the complaint propensity, citizens' monitoring activity in Heyes (2002) is given and not endogenous, in contrast to the present model. Secondly, in filtered enforcement, polluters are only sanctioned - in terms of our model - after investigations. A better signal then crowds out the regulator's propensity to investigate reports. By contrast, in our model the regulator investigates every report and it is the increase in reports that crowds out inspections that are conditional on 'no report.'

A similar difference occurs between our setting and the one analyzed by Bandyopadhyay and Chatterjee (2010). In a crime context they consider a situation of peer monitoring between two groups and subsequent reports to the police. In this context, false *positive* reports are important. If two groups have different abilities to assess whether an observation indeed is based on an illegal act, the police responds to the *larger bias* in reporting by lowering investigations conditional on reports. By contrast, the regulator in our model *substitutes* own inspections through more (and more accurate) reports.

Finally, Garoupa (2001) focuses on the crowding-in of investigations due to reporting. There, subsidizing reports - and thus more reporting - is always beneficial because in the absence of reporting, expected punishment for perpetrators is assumed to be negligible. Again, the models and mechanisms differ. Whereas in the present model the possibility of avoiding harm provides an incentive for citizens to report, there, victims only report if they are compensated. Second, victims possess a perfect monitoring technology, while the technology is imperfect in the present paper. Third, and most important, the regulator's strategy set differs. In Garoupa (2001), the regulator jointly determines both probabilities of sanctioning conditional on a report and conditional on no report using a single measure, namely enforcement expenditure. As a consequence, when fixing enforcement expenditure the regulator pushes both probabilities into the same direction. Our model differs in that the regulator can set the inspection and the investigation probability independently, allowing both to move into the same direction or - as is important for our results - to diverge.

To summarize the contribution of the present analysis is threefold: First, it is the first model to our knowledge that explicitly takes imperfections in citizens' monitoring technology into account and analyzes the consequences that arise if better technologies become available. Second, it considers the subtle relationship between citizens' incentives to report infractions and regulatory investigations *and* inspections in a game theoretic setup. Third, the paper demonstrates a novel mechanism by which citizen monitoring and reporting can have undesirable and unexpected crowding effects.

10.2 Relaxing assumptions

How robust is the result to changes in some modeling assumptions? First, we assumed that the citizen does not tell the regulator whether he sampled when the assay indicates 'no pollution.' Deviating from this assumption does not necessarily alter the results, but involves a different structure of information sets. Alongside the regulator's single-node information set where the assay indicated 'pollution', two other sets would emerge. One contains the two nodes where the sample correctly or falsely indicates 'no pollution'. say H_s, and the other contains the two nodes where the regulator knows that the sample was not taken, say H_{ns}. At H_{ns} the regulator would have to decide whether to inspect as well, adding a new variable, say $\hat{p}_{ins}$. Focussing on equilibria with $\beta = 1$ means that H_{ns} would not be reached in equilibrium and p^*_{ins} - the equilibrium choice at H_s - as well as α^* would remain unchanged. Whether this is an equilibrium depends on the restrictions one puts on beliefs off the equilibrium path and the (resulting) regulator's belief at H_{ns}. Given this belief $\hat{p}_{ins}$ must be sequential rational for the regulator and at the same time be sufficiently small for $\beta = 1$ still be a best response.

Second, we assumed that the citizen does not lie, i.e. he truthfully reveals whether the assay indicated 'pollution'. This assumption, while capturing the main focus of the literature on citizen monitoring, may not be reasonable. Given the possibility of false negative samples, the citizen cannot be sure to suffer no harm if the assay indicates 'no pollution'. This provides an incentive for wrongfully reporting 'pollution'.[1] However, one can justify the truth-telling assumption on two grounds. On the one hand, note that the regulator investigates reports. Because we abstract from false positive results the regulator knows that the citizen lied if he reported pollution but investigations reveal the opposite allowing to fine wrongful reports. If the fine was sufficiently large the citizen would not lie. On the other hand, the one-shot game analyzed can be considered to be a snapshot of a repeated interaction. The possibility to lie can then have several effects that give the citizen an incentive to tell the truth. The regulator might react to the possibility of lies by choosing a smaller investigation probability leading to more pollution as well as to less recovery both causing more harm. Moreover, in a repeated interaction the regulator might stick to strategies that initially feature investigations with probability one but where he refuses to investigate (at least for some time) if the citizen failed to tell the truth.

[1] See also Takáts (2009) who considers excessive reporting in the context of money laundering.

11 Conclusion of part II

As the paper substantiates, the intuition that a higher monitoring quality in citizen monitoring programs is naturally associated with more compliance, less harm, and higher welfare for the concerned population may not hold. Instead, enhancing the citizen's ability to infer whether a firm polluted can worsen environmental quality. This holds even in a situation where a better monitoring technology can be applied without higher costs. The reason is the counterintuitive result that such an improved technology can lead to more harm caused by pollution. Nevertheless, the proposition shows that employing a better technology can be desirable even if its adoption is accompanied by lower environmental quality. This would be the case if the savings in expected inspection and compliance costs outweigh the aggregate increase in the other elements of the regulator's objective, i.e. expected harm, expected recovery and expected investigation costs.

One important implication and future area of research is the relationship between progress in monitoring quality, e.g. through technological innovations, and the incentives to adopt. Suppose that a better monitoring technology would be associated with higher welfare so that its adoption is desirable from society's point of view. The problem is then that it is not the regulator but the citizen who uses the monitoring device. Although it is beneficial for the citizen to use *some* monitoring device he is not indifferent between monitoring technologies with differing error probabilities. In the full sampling equilibrium expected harm increases if the error probability gets smaller. Thus, the citizen is worse off if he uses a better monitoring device. If the citizen then could choose a device he would choose one with a high error probability (assuming that one with $q > \frac{c_{com}}{c_{rec}}$ is not available). This raises the question how the better technology can be employed if desirable. Such an analysis should also take into account that there might be a relationship between the citizen's monitoring accuracy and sampling costs. The citizen then can have an additional choice variable, i.e. he can choose how much to spend on sampling and thereby determine the error probability.

Part III

Criminalizing Environmental Offences: When The Prosecutor's Helping Hand Hurts

12 Introduction to part III

Environmental regulation in Europe has changed substantially in the last years. Two trends that received considerable attention stand out. The first trend is the mobilization of the apparatus of criminal prosecution in pursuit of environmental offenders. The second trend is the increasing reliance on self-reporting by polluters.

In contrast to standard regulatory procedures, *criminal prosecution* provides access to the full sanctioning regime of criminal law. German environmental law takes a particularly prominent role in this context. In the European Union this trend resulted in the EU directive 2008/99/EC '*on the protection of the environment through criminal law*'. The economic intuition guiding this procedure stems from the standard model of crime and punishment (Becker 1968)[1]: Risk-neutral, rational agents will commit an offence if and only if the benefits exceed the expected punishment. Therefore, increasing punishment, imposed at relatively low costs, allows to substitute relatively costly inspections without diluting deterrence. Similarly, if the end is to improve environmental quality, increasing punishment for environmentally harmful activities - while keeping the probability of conviction constant - reduces the attractiveness of offences and yields fewer violations and thus less harm. The economic literature on crime has demonstrated that there is a variety of good reasons for being skeptical about the universal benefits of tighter sanctions (e.g. Stigler 1970, Andreoni 1991, Heyes 1996)[2].

[1]See Posner (1985), Fenn and Veljanovski (1988), Ogus and Abbot (2002), Faure and Visser (2004), Bowles et al. (2008), and Faure et al. (2009) for a discussion of criteria that help to assess the relative (dis-) advantages of the criminal law versus other means to controll harmful activities and / or enforce norms, e.g. tort law, administrative proceedings, and taxes.

Garoupa and Gomez-Pomar (2004) argue that there are circumstances where it is optimal to use criminal sanctions *additionally* to regulatory fines.

[2]See also Garoupa (1997) for a survey.

What the literature has not sufficiently considered, however, is that drawing up particular statutes that specify the criminal act and the tariffs this act attracts is only one of two building blocks required when introducing criminal sanctions. The other is institutional and arises from the specific prosecutorial and judicial mandates that are enshrined in laws and norms set outside the realm of environmental enforcement. On the one hand, codes of criminal procedure in many EU states rule that prosecutors have to follow the legality principle. This requires prosecuting every (potential) crime that comes within their competence - in contrast to the opportunity principle that hands the prosecutor discretion over whether to pursue a crime or not. On the other hand, when deciding which penalty to impose on convicted perpetrators courts cannot and do not exclusively rely on incentive considerations and economic reasoning. Sentencing also follows e.g. minimum and maximum penalties for certain acts, attitudes of justice and fairness, size of sanctions for other acts than those being environmentally harmful, and even sometimes the judge's personal preferences.[3]

The second trend is the increasing reliance on *self-reporting*. In many countries carrying out self-monitoring is mandatory (Farmer 2007). A growing number of legislations prescribe firms to report (accidental) emissions to regulatory authorities. National 'Pollutant Release and Transfer Registers' and its European counterpart (E-PRTR) that followed the less comprehensive 'European Pollutant Emission Register' (EPER) are illustrative. Previous works have identified several benefits arising from self-reporting. Potential benefits from self-reporting can be lower enforcement and risk bearing costs (Kaplow and Shavell 1994), lower inspection costs (Malik 1993), remediation benefits due to e.g. clean-up of contaminated sites (Innes 1999), harsher sentences for those not reporting (Innes 1999 and similar Livernois and McKenna 1999), correction of overdeterrence (Innes 2000), avoiding avoidance activities (Innes 2001), and a higher probability of successful citizen suits (Langpap 2008).

In this paper we jointly analyze both trends in a single model. We show that there are circumstances in which criminalizing environmental offences retracts the benefits from self-reporting. The simple model features a single firm and a

[3]See for example Easterbrook (1983) and Schulhofer (1988) who - among many others - debate whether prosecutorial and sentencing discretion can promote efficiency.

regulator. The firm undertakes a risky activity that might lead to an accident causing environmental harm. By excerting care it can influence the probability that such an accident occurs. The regulator's mandate is to 'care about the environment', i.e. his objective is to minimize expected environmental damages. In doing so he chooses a regulatory policy that consists of (i) the probability of inspection, (ii) a fine for the firm if it does not report an accident, and (iii) a fine for a truthfully reported accident. Additionally, the regulator orders clean-up that removes damages except an unrecoverable fraction. An unconstrained regulator could minimize expected damages simply by setting all three variables to their respective maximum. The model focuses on the more interesting and realistic case of a budget-constrained regulator. In terms of the gains from self-reporting the model sets remediation benefits center stage as they are closest to the harm minimizing motive. A constrained budget means that permanent inspections are not feasible. This in turn implies that the firm's fine in case of an accident - whether reported or not - is less than maximal and so is the care excerted. Raising penalties by imposing criminal sanctions, therefore, should lead to an increase in environmental quality. This paper shows that this intuitive conclusion does not necessarily hold if the institutional framework leads to less self-reporting.

If environmental offences are not subject to criminal sanctions, it is optimal - in terms of environmental quality - that a budget constrained regulator incentivizes the firm to report. This is because the fine for a reported accident is the same as the expected fine in case of no report (Innes 1999) yielding identical levels of care. However, a report implies certain clean-up contrary to uncertain recovery if the firm does not report. The regulator fine-tunes his policy so that the firm has an incentive to report an accident. This already points to the reason why adding the prosecutorial and judicial system to environmental regulation can dilute the incentives to self-report. Prosecutors as well as courts are bounded by procedural and sentencing rules and may disable the regulator's ability to fine-tune his policy. The criminal system provides harsher penalties. The firm's incentives, however, are determined by the *absolute* levels of penalties but also by the *difference* in the (expected) penalties for a reported and unreported accident. On the one hand, the level of care depends on the (expected) penalty. On the other hand, the reporting decision depends upon the difference between the certain fine after a report and the expected fine for not reporting. The institutional limitations that accompany the judicial system can prevent a policy that causes the firm to report, thus removing remediation benefits.

The paper proceeds as follows. The next section describes the basic model. Section 14 compares reporting and no reporting without criminalization and section 15 adds the prosecutor. The results are compared in section 16. Section 17 concludes.

13 The basic model

The basic model considers a risk-neutral firm and an environmental agency, henceforth the regulator. The firm undertakes a risky activity that might lead to an accident causing damages d. By spending an amount of x on excerting precautionary effort the firm can influence the probability that an accident occurs. This probability is $\sigma(x)$ with $\sigma_x(x) < 0$, $\sigma_{xx}(x) > 0$. The firm perfectly observes whether an accident happened. In case of an accident it can report it to the regulator.

The regulator cannot observe the firm's exerted care. However, by conducting costly monitoring in the absence of a report the regulator can identify whether an accident happened. The regulator is budget constrained, i.e. $b < \mu$ where b is the regulator's budget and μ are the costs of 24/7 monitoring. In the basic model the regulator has three policy variables at hand: first, he chooses to inspect with frequency p if the firm does not report an accident. Second, he imposes a fine if the firm reports an accident and, third, imposes a potentially differing fine if the firm does not report but inspections reveal that an accident happened. Imposing fines is costless. Additionally to paying a fine, the firm is forced to recover damages of an accident at its own expense, independent of whether a report or inspections reveal that the accident happened. The costs of recovery are the same independent of whether it is ordered after a report or after inspections. Denote the firm's total cost after an accident in case it reports f_1 and f_2 in case of inspections. These two measures include the respective fine as well as recovery costs. As recovery costs are exogenous and the same in both situations we can treat f_1 and f_2 to be directly under the regulator's control and term them fines in the following. Both fines cannot be arbitrarily large, i.e. $f_i \leq \bar{f}_i$ $i = 1, 2$, where

$\bar{f}_i$ is the respective largest possible fine the regulator can impose.[1] Recovery eliminates damages except a fraction of δ.

The firm's objective is to minimize costs. If the firm reports an accident these costs C_r are

$$C_r = x + \sigma(x) f_1. \tag{III.1}$$

If instead it does not report an accident its costs C_{nr} are

$$C_{nr} = x + \sigma(x) p f_2. \tag{III.2}$$

Independent of whether an accident happens the firm incurs the costs of excerting care. Additionally, if an accident happens it either pays the certain fine f_1 if it does report or the expected fine pf_2 if it does not.

Following e.g. Garvie and Keeler (1994) and Heyes and Rickman (1999) we assume that the regulator's objective is to minimize expected damages.[2] If the firm reports these damages are D_r:

$$D_r = \sigma(x) \delta d. \tag{III.3}$$

If an accident happens and the firm reports the regulator suffers unrecoverable damages δd. If instead the firm does not report damages D_{nr} are

$$\begin{aligned} D_{nr} &= \sigma(x)\left[(1-p) d + p\delta d\right] \\ &= \sigma(x)\left[1-(1-\delta) p\right] d. \end{aligned} \tag{III.4}$$

If the accident is not reported the regulator suffers total damages if he does not

[1] The maximum feasible fine can for instance be defined by the legal framework. Alternatively, both fines can be constrained by the firm's assets w. In that case necessarily $\bar{f}_1 = \bar{f}_2 = w$. However, we do not restrict the analysis to the special case where $\bar{f}_1 = \bar{f}_2$.

[2] It is well understood that in many countries the mandate of environmental agencies is environmental protection (Farmer 2007). Others assuming that the regulator's objective is to minimize harm (or maximize environmental quality) are e.g. Heyes (1996), Hansen et al. (2006), and Jost (1997a). Jones and Scotchmer (1990) consider the case of an agency whose goal is to maximize benefits of compliance and analyze the resulting impacts on the budget setting process.

See Heyes and Kapur (2009b) and Keeler (1995) for discussions of different regulatory objectives. Firestone (2002) finds empirical support for harm minimizing regulators. See also Firestone (2003) for a discussion of how the EPA would operate under certain motivations.

inspect and unrecoverable damages only if he inspects. Stated differently, the second line in (III.4) says that the regulator suffers damages except the fraction that is recovered $(1 - \delta)$ if he inspects. Having described the basic model we now derive the firm's choice and the optimal policy.

14 Monitoring and enforcement without the prosecutor

Before we analyze the impact of adding the prosecutorial system to the regulation of harmful activities by a budget constrained regulator we derive the optimal policy in the absence of the prosecutor. This serves as a benchmark for comparing criminalization with sole regulatory monitoring and enforcement. The analysis shows that the optimal policy depends on the relative size between the maximum fine in case the firm reports $\bar{f}_1$ and the maximum feasible expected fine if the firm does not report $\frac{b}{\mu}\bar{f}_2$.

The model involves two stages. At the first stage the regulator specifies a policy $\{p, f_1, f_2\}$[1] whereas at the second stage the firm chooses the level of care and whether to report an accident. The regulatory policy can incentivize the firm to report or not. When solving the model we differentiate according to the reporting decision the policy induces. For both cases we first analyze the firm's decision about the optimal level of care given the optimal policy. Thereafter, we derive the optimal policy that induces the firm's optimal level of care. Having derived both policies - the one that optimally induces reporting and the one that optimally does not - we compare both outcomes and analyze which case the regulator prefers and thus implements. Optimal choices are marked by an asterisk.

[1]Denoted $\{p_r, f_{1,r}, f_{2,r}\}$ if it induces the firm to report and $\{p_{nr}, f_{1,nr}, f_{2,nr}\}$ if not.

14.1 Policy with reporting

Suppose that the regulator set the optimal policy $\left\{p_r^*, f_{1,r}^*, f_{2,r}^*\right\}$ that induces the firm to report an accident. This must satisfy

$$f_{1,r}^* \leq p_r^* f_{2,r}^* \tag{III.5}$$

for reporting to be superior compared to not reporting. If (III.5) is satisfied the firm's optimization problem is

$$\min_x x + \sigma(x) f_{1,r}^*.$$

The FOC

$$1 + \sigma_x(x_r^*) f_{1,r}^* = 0 \tag{III.6}$$

defines the optimal choice $x_r^* = x_r^*\left(f_{1,r}^*\right)$ with $\frac{dx_r^*}{df_{1,r}} > 0$.[2] If the fine $f_{1,r}^*$ increases the optimal level of care increases because the marginal benefits in terms of the penalty avoided increase as well.

Given the firm's reaction function x_r^* the regulator's optimization problem is

$$\min_{p_r, f_{1,r}, f_{2,r}} \sigma(x_r^*) \delta d$$

s.t.

$$\begin{gathered} p_r \mu \leq b \\ f_{1,r} \leq \bar{f}_1 \\ f_{2,r} \leq \bar{f}_2 \\ 1 + \sigma_x(x_r^*) f_{1,r} = 0 \\ f_{1,r} \leq p_r f_{2,r}. \end{gathered}$$

The first constraint is the regulator's budget constraint, the second and third are the restrictions on the implementable fines, the fourth defines the firm's reaction function and the last constraint is the reporting condition. The objective implies

[2]This can easily be verified by applying the total differential on the FOC.

that the regulator wants the level of care x_r^* to be as large as possible to miminize the probability of an accident. As the level of care is increasing in $f_{1,r}$ this fine has to be as large as possible as well. The reporting condition calls for a discount on the fine after a report $f_{1,r}$ as this is imposed with certainty compared to the fine for not reporting $f_{2,r}$ which is imposed only when the firm is inspected. Two situations are possible: First, the maximum fine for a reported accident $\bar{f}_1$ is small in the sense that $\frac{b}{\mu}\bar{f}_2 \geq \bar{f}_1$. In that case setting $f_{1,r}$ to its maximum, i.e. $f_{1,r}^* = \bar{f}_1$, is possible because the regulator is able to set the expected fine for not reporting above this level. The optimal inspection frequency p_r^* and the optimal fine $f_{2,r}^*$ have to fulfill the reporting condition and w.l.o.g. we set $p_r^* = \frac{b}{\mu}$ and $f_{2,r}^* = \bar{f}_2$. Second, if $\bar{f}_1$ is relatively large in the sense that $\frac{b}{\mu}\bar{f}_2 < \bar{f}_1$ the regulator cannot fully exploit the deterrence power of $f_{1,r}$. He has to offer the firm a discount in the fine for reporting because $\bar{f}_2$ and the budget b prevent to raise the expected fine for not reporting above $\overline{f}_1$. The optimal policy sets the expected fine for not reporting to its maximum and sets the highest f_1 that fulfills the reporting condition, i.e. $p_r^* = \frac{b}{\mu}$, $f_{1,r}^* = \frac{b}{\mu}\bar{f}_2$, $f_{2,r}^* = \bar{f}_2$.[3] We summarize this in

Proposition III.1 *The optimal regulatory policy that lets the firm report an accident is*

$$\left\{p_r^*, f_{1,r}^*, f_{2,r}^*\right\} = \left\{ \begin{array}{ll} \left\{\frac{b}{\mu}, \bar{f}_1, \bar{f}_2\right\} & \text{if } \frac{b}{\mu}\bar{f}_2 \geq \bar{f}_1 \\ \left\{\frac{b}{\mu}, \frac{b}{\mu}\bar{f}_2, \bar{f}_2\right\} & \text{if } \frac{b}{\mu}\bar{f}_2 < \bar{f}_1 \end{array} \right. .$$

Having derived the optimal poliy inducing reporting we now turn to the case where the firm does not report.

[3]In this second case where $\frac{b}{\mu}\bar{f}_2 - \bar{f}_1 < 0$ the actual fine imposed in case of a report can be negative. To see this, recall that the measures f_1 and f_2 do not only entail the penalty for an accident but also recovery costs. Denote the actual penalties f_1' and f_2' respectively and recovery costs k. The (binding) reporting condition then is $f_1' + k = \frac{b}{\mu}\left(\bar{f}_2' + k\right)$ so that the penalty actually imposed for a reported accident is $f_1' = \frac{b}{\mu}\left(\bar{f}_2' + k\right) - k$ which, for small budgets, can be negative. Therefore, if b is small, the regulator would have to pay a subsidy to a reporting firm which would further reduce the regulator's budget available for inspections. In the following, we abstract from the possibility that imposed fines can be negative, i.e. we assume that the regulator's budget is sufficiently large.

14.2 Policy without reporting

Having described how to optimally incentivize the firm to report an accident we now turn to the case where the firm does not report. The firm will not report an accident if and only if the policy $\left\{p_{nr}^*, f_{1,nr}^*, f_{2,nr}^*\right\}$ satisfies the no reporting condition

$$f_{1,nr}^* > p_{nr}^* f_{2,nr}^*. \tag{III.7}$$

Given this, the firm's optimization problem is

$$\min_x x + \sigma(x) p_{nr}^* f_{2,nr}^*$$

and the FOC defines its optimal choice x_{nr}^*:

$$1 + \sigma_x(x_{nr}^*) p_{nr}^* f_{2,nr}^* = 0. \tag{III.8}$$

Then $x_{nr}^* = x_{nr}^*\left(p_{nr}^*, f_{2,nr}^*\right)$ with $\frac{dx_{nr}^*}{dp_{nr}^*}, \frac{dx_{nr}^*}{df_{2,nr}^*} > 0$.

Given this reaction function x_{nr}^* the regulator's problem becomes

$$\min_{p_{nr}, f_{1,nr}, f_{2,nr}} \sigma(x_{nr}^*) \left[1 - (1-\delta) p_{nr}\right] d$$

s.t.

$$\begin{aligned} p_{nr}\mu &\leq b \\ f_{1,nr} &\leq \bar{f}_1 \\ f_{2,nr} &\leq \bar{f}_2 \\ 1 + \sigma_x(x_{nr}^*) p_{nr} f_{2,nr} &= 0 \\ f_{1,nr} &> p_{nr} f_{2,nr} \end{aligned}$$

The objective requires the level of care to be as large as possible. Again, two situations can occur. First, $\bar{f}_1$ is large, i.e. $\frac{b}{\mu}\bar{f}_2 < \bar{f}_1$. The regulator then sets $p_{nr}^* = \frac{b}{\mu}$ as this (i) maximizes the level of care and (ii) minimizes damages that are not recovered. Additionally, he sets $f_{2,nr}^* = \bar{f}_2$ to maximize the level of care. The no reporting condition requires $f_{1,nr}^* > \frac{b}{\mu}\bar{f}_2$ and we set $f_{1,nr}^* = \bar{f}_1$.

Second, if instead $\bar{f}_1$ is small, i.e. $\frac{b}{\mu}\bar{f}_2 \geq \bar{f}_1$, it is not possible to set $pf_{2,nr}$ to its maximum because otherwise the maximum fine for a reported accident is too small to prevent reporting. The expected fine, while respecting the no reporting condition, is maximized by setting $f^*_{1,nr} = \bar{f}_1$, $p^*_{nr} = \frac{b}{\mu}$, $f^*_{2,nr} = \frac{\mu}{b}\bar{f}_1 - \eta$ with η arbitrarily close to zero.[4]

Thus, we get

Proposition III.2 *The optimal regulatory policy that lets the firm not report an accident is*

$$\left\{p^*_{nr}, f^*_{1,nr}, f^*_{2,nr}\right\} = \begin{cases} \left\{\frac{b}{\mu}, \bar{f}_1, \frac{\mu}{b}\bar{f}_1 - \eta\right\} \textit{ with } \eta \textit{ arbitrarily close to zero if } \frac{b}{\mu}\bar{f}_2 \geq \bar{f}_1 \\ \left\{\frac{b}{\mu}, \bar{f}_1, \bar{f}_2\right\} \textit{ if } \frac{b}{\mu}\bar{f}_2 < \bar{f}_1 \end{cases}.$$

14.3 Reporting versus no reporting

Given the optimal reporting and no reporting policies, we can now determine when the regulator prefers that the firm reports an accident. We have to consider two cases. One where $\bar{f}_1 \leq \frac{b}{\mu}\bar{f}_2$ and one where $\bar{f}_1 > \frac{b}{\mu}\bar{f}_2$.

Small $\bar{f}_1$ We first consider the case where $\bar{f}_1$ is small, i.e. $\frac{b}{\mu}\bar{f}_2 \geq \bar{f}_1$. The firm's level of care if the policy makes the firm report an accident x^*_r is given by

$$1 + \sigma_x\left(x^*_r\right)\bar{f}_1 = 0$$

whereas the no reporting level x^*_{nr} is defined by

$$\begin{aligned} 1 + \sigma_x\left(x^*_{nr}\right)\frac{b}{\mu}\left(\frac{\mu}{b}\bar{f}_1 - \eta\right) &= 0 \Leftrightarrow \\ 1 + \sigma_x\left(x^*_{nr}\right)\bar{f}_1 - \frac{b}{\mu}\eta &= 0 \end{aligned}$$

[4]Depending on the parameters it could also be that $p^*_{nr} < \frac{b}{\mu}$. However, optimality requires that in the limit the expected penalty for not reporting equals $\bar{f}_1$ (independent of the precise values for p^*_{nr} and $f^*_{2,nr}$). Thus, in the limit $x^*_r = x^*_{nr}$. Below it is shown that this is sufficient for the main result to hold.

with η arbitrarily close to zero, so that the firm excerts insignificant more care if the regulator chooses the reporting policy. The reason why the levels of care are virtually the same in both situations is the following: In both cases the regulator sets the (expected) penalty to its feasible maximum as this yields the highest level of care. The reporting policy features $\bar{f}_1$. Under the no reporting policy the expected penalty for an accident not reported has to be as close as possible to $\bar{f}_1$. Thus, in the limit the expected fine for not reporting equals the fine in case of a report and the respective levels of care are the same.

Denote the difference between the outcomes if $x = x_r^*$ and $x = x_{nr}^*$ as $\Delta\left(x_r^*, x_{nr}^*\right)$ so that if $\Delta\left(x_r^*, x_{nr}^*\right) < 0$ the regulator prefers that the firm reports and vice versa. We get

$$\begin{aligned}\Delta\left(x_r^*, x_{nr}^*\right) &= \sigma\left(x_r^*\right)\delta d - \sigma\left(x_{nr}^*\right)\left[1-(1-\delta)\,p_{nr}^*\right]d \\ &\overset{x_{nr}^*->x_r^*}{\to} \sigma\left(x_r^*\right)\left\{\delta - 1 + (1-\delta)\frac{b}{\mu}\right\}d \\ &= \sigma\left(x_r^*\right)(1-\delta)\left(\frac{b}{\mu}-1\right)d < 0.\end{aligned}$$

Thus, if $\frac{b}{\mu}\bar{f}_2 \geq \bar{f}_1$ the regulator implements the reporting policy. The reason is that the level of care is virtually the same but in case of reporting the regulator realizes remediation benefits with certainty whereas in the opposite case these benefits are only realized with a probability smaller than one.[5]

Large $\bar{f}_1$ Second, consider the case where $\bar{f}_1$ is large, i.e. $\frac{b}{\mu}\bar{f}_2 < \bar{f}_1$. The two levels of care x_r^* and x_{nr}^* are defined by

$$1 + \sigma_x\left(x_r^*\right)\frac{b}{\mu}\bar{f}_2 = 0$$

and

$$1 + \sigma_x\left(x_{nr}^*\right)\frac{b}{\mu}\bar{f}_2 = 0$$

[5]The second part of this argument was first made by Innes (1999). In his setup, the optimal levels of care differ between a reporting and a no reporting regime. The reason is that Innes assumes that the regulator maximizes welfare thus also taking enforcement expenditures and costs of care into account.

respectively, so $x_r^* = x_{nr}^*$. The relative advantage for the regulator of inducing reports $\Delta(x_r^*, x_{nr}^*)$ is then

$$\begin{aligned}
\Delta(x_r^*, x_{nr}^*) &= \sigma(x_r^*)\,\delta d - \sigma(x_{nr}^*)\left[1-(1-\delta)\,p_{nr}^*\right]d \\
&\overset{x_r^*=x_{nr}^*}{=} \sigma(x_r^*)\left\{\delta - 1 + (1-\delta)\frac{b}{\mu}\right\}d \\
&= \sigma(x_r^*)(1-\delta)\left(\frac{b}{\mu}-1\right)d < 0.
\end{aligned}$$

Therefore, if $\frac{b}{\mu}\bar{f}_2 < \bar{f}_1$ the regulator implements the reporting policy as well. The reason is the same as in the case where $\bar{f}_1$ is small: The levels of care are the same but reporting yields remediation benefits with certainty. So we have

Proposition III.3 *A policy that incentivizes the firm to report accidents minimizes environmental damages.*[6]

[6]Taking into account punishment costs but neglecting remediation benefits, Malik (1993) shows that a reporting regime is not necessarily welfare enhancing. The reason is that on the one hand the firm is inspected less often but on the other hand penalties are imposed more often. Whether reporting is desirable then depends on, among other factors, on the relative costs of inspections and punishment.

15 Monitoring and enforcement with the prosecutor

In the previous section we demonstrated that a budget-constrained regulator whose objective is to minimize environmental damages prefers a policy where accidents are reported. This holds independently of the relative size of the maximum (expected) fines the regulator can impose.

In this section we assume that another enforcement authority complements the regulatory process. This is not an environmental agency but rather a "pure" enforcement authority. The task of this agency is to pursue and punish violators. The examples we have in mind are EU countries being obliged to implement a system of criminal santions for environmental offences.[1] In Germany, for instance, several agencies ('Gewerbeaufsichtsämter', 'Genehmigungsdirektionen' etc) are (among other things) responsible for environmental quality. On the other hand, public prosecutors are responsible for criminal proceedings and are operating under the so called legality principle (§ 152 (2), German Criminal Procedure Order). Fisher (2009) explains this concept for Germany as follows:

> "The [State Attorney's Office] is obliged to intervene [..] with regard to all [criminal offences] capable of prosecution, so far as (sufficient factual clues) exist (the so-called *Legalitätsgrundsatz* (legality principle), as opposed to the [..] opportunity principle, whereby, in certain cases the [State Attorney's Office] has a discretion not to pursue the matter."

The legality principle says that the police and prosecutors are compelled to

[1] EU directive 2008/99/EC from December 6th, 2008.

pursue any potential violation they get informed about.[2] The public prosecutor then accuses potential perpetrators in court which then, in case the court finds the violator being guilty, imposes sanctions. Other countries' Criminal Procedure Orders contain similar features. Examples are Austria (§ 34, Austrian Criminal Procedure Order), Switzerland (Art. 7, Swiss Criminal Procedure Order) and other civil law countries. The pattern of the legality principle is similar in these countries. However, they differ in the relative importance of the legality principle compared to the opposing opportunity principle.[3] In common law countries the legality principle is rather unknown or at least of minor importance. There, public prosecutors and often also the police have a high degree of discretionary power when deciding whether to prosecute a certain case.

In terms of our model criminalizing environmental offences in combination with the legality principle means that the regulator - who is not authorized to prosecute and to impose criminal sanctions - reports any violation he gets informed about to the prosecutor.[4] The prosecutor then brings the case to court. We assume that the resulting fines are exogenous and not (necessarily) based on incentive compatibility considerations with respect to a firm's reporting behavior.

[2]This meaning of the term "legality principle" must not be mixed up with the principle "nulla poena sine lege" which is the principle of legality but sometimes is also called legality principle.

[3]For a more detailed description of the legality and the opportunity principle in Germany see e.g. Kühne (2010, 198-201) and Weigend (1978).

[4]We assume that the regulator reports every accident to the prosecutor. This assumption can be justified on two grounds: First, this assumption follows the theoretical logic inherent in the criminalization of certain acts. Allowing the imposition of criminal sanctions is meaningless if those who are responsible for doing so are virtually never informed about a crime. Second, we demonstrate below that criminalization might lead to undesirable effects in terms of more damages. This raises the question why a regulator responsible for environmental quality will ever report violations to the prosecutor. Nevertheless, we assume that he does so because in the 'backround' an incentive mechanism is at work that induces the regulator to pass his information over to the prosecutor (see the huge delegation literature for discussions about how to control agency behavior, e.g. McCubbins and Schwartz 1984, Weingast 1984, McCubbins et al. 1987, 1989, Calvert et al. 1989).

In fact, there is evidence that regulators are aware that imposing criminal sanctions can have negative effects. As regulators mostly follow a prospective approach they are more interested in avoiding and reducing harm compared to sanctioning. Thus, they rather follow the "cooperation instead of confrontation" principle and report incidents only infrequently (Schall 1990). Nevertheless, to demonstrate that criminalization can have undesirable effects (which seems to be understood by regulators) we assume that the regulator follows the advice to report incidents.

They are rather in line with the broader framework of criminal sanctions and are embedded in the system of sanctions for all other possible crimes. Thus, criminal sanctions are based, for instance, on grounds of marginal deterrence (Stigler 1970, Friedman and Sjostrom 1993, Mookherjee and Png 1994), fairness and justice (Miceli 1991, Polinsky and Shavell 2000a). Denote the exogenous fines by $\hat{f}_1$ and $\hat{f}_2$ respectively.[5] The only policy variable that remains under the regulator's control is the inspection frequency, now denoted $\hat{p}$. To analyze the regulator's optimal policy we proceed in the same way as in the previous section.

15.1 Reporting in the presence of the prosecutor

Given the optimal inspection frequency $\hat{p}^*$ the firm will report an accident if and only if

$$\hat{f}_1 \leq \hat{p}_r^* \hat{f}_2.$$

In that case the firm's optimization problem is

$$\min_x x + \sigma(x) \hat{f}_1$$

and the FOC

$$1 + \sigma_x(\hat{x}_r^*) \hat{f}_1 = 0$$

defines the firm's optimal choice $\hat{x}_r^* = \hat{x}_r^*\left(\hat{f}_1\right)$ with $\frac{d\hat{x}_r^*}{d\hat{f}_1} > 0$.

As the firm's reaction function in the presence of the prosecutor and in case the policy induces reporting does only depend on $\hat{f}_1$, which is outside the regulator's control, the regulator has no influence on $\hat{x}_r^*$. The only policy variable the regulator sets is the inspection frequency which influences the firm's reporting decision. For the firm to report an accident the inspection frequency has to be sufficiently high, i.e.

$$\hat{p}_r^* \geq \frac{\hat{f}_1}{\hat{f}_2}.$$

[5] See also Langpap (2007) who endogenizes regulatory penalties but treats fines after a citizen suit to be exogenously set by the court. Given that judges and legislatures can have differing preferences Miceli (2008) discusses how much discretion judges should be given when deciding about sentencing.

Contrary to the previous section where the prosecutor was not involved in the regulatory process the regulator might now not be able to induce the firm to report. Two conditions must be satisfied so that there exists a policy that leads to a report. First, $\hat{f}_2 \geq \hat{f}_1$, which we reasonably assume in the following, and, second, given $\hat{f}_2 \geq \hat{f}_1$, the regulatory budget must be high enough to raise the expected sanction for not reporting above the level of the certain sanction for reporting, i.e. $\frac{b}{\mu} \geq \frac{\hat{f}_1}{\hat{f}_2}$. Stated differently, for reporting to be feasible $\hat{f}_1$ must be small in the sense that $\frac{b}{\mu}\hat{f}_2 \geq \hat{f}_1$. Then any inspection frequency $\hat{p}_r^* \in \left[\frac{\hat{f}_1}{\hat{f}_2}, \frac{b}{\mu}\right]$ lets the firm report and w.l.o.g. we set $\hat{p}_r^* = \frac{\hat{f}_1}{\hat{f}_2}$. If instead $\hat{f}_1$ is large the regulator's budget constraint hinders the regulator to raise the expected sanction for not reporting above the certain fine for reporting. In that case a policy inducing reporting is not feasible if the prosecutor is present.

15.2 Not reporting in the presence of the prosecutor

In the presence of the prosecutor the firm will not report if and only if

$$\hat{f}_1 > \hat{p}_{nr}^* \hat{f}_2.$$

The firm then solves

$$\min_x x + \sigma(x)\, \hat{p}_{nr}^* \hat{f}_2$$

which yields

$$1 + \sigma_x(\hat{x}_{nr}^*)\, \hat{p}_{nr}^* \hat{f}_2 = 0$$

and so $\hat{x}_{nr}^* = \hat{x}_{nr}^*\left(\hat{p}_{nr}^*, \hat{f}_2\right)$ with $\frac{d\hat{x}_{nr}^*}{d\hat{p}_{nr}^*}, \frac{d\hat{x}_{nr}^*}{d\hat{f}_2} > 0$. Contrary to the case of reporting the regulator now can influence the level of care because this is affected by the inspection frequency.

The regulator's problem is then

$$\min_{\hat{p}_{nr}} \sigma(\hat{x}_{nr}^*)\left[1 - (1-\delta)\,\hat{p}_{nr}\right] d$$

s.t.

$$\hat{p}_{nr}\mu \leq b$$
$$1 + \sigma_x\left(\hat{x}^*_{nr}\right)\hat{p}_{nr}\hat{f}_2 = 0$$
$$\hat{f}_1 > \hat{p}_{nr}\hat{f}_2.$$

The objective requires $\hat{p}_{nr}$ to be as large as possible to maximize the level of care and to minimize damages not recovered. At the same time $\hat{p}_{nr}$ must be smaller than $\frac{\hat{f}_1}{\hat{f}_2}$ to meet the no reporting condition. Two situations are possible: If $\hat{f}_1$ is large, i.e. if $\frac{b}{\mu}\hat{f}_2 < \hat{f}_1$, then $\hat{p}^*_{nr} = \frac{b}{\mu}$. If instead $\hat{f}_1$ is small the regulator sets $\hat{p}^*_{nr} = \frac{\hat{f}_1}{\hat{f}_2} - \epsilon$ with ϵ arbitrarily close to zero to meet the no reporting condition.

We summarize the optimal policies that induce reporting and not reporting respectively in the presence of the prosecutor in

Proposition III.4 *In the presence of the prosecutor, then*

1. *if $\hat{f}_1$ is large ($\frac{b}{\mu}\hat{f}_2 < \hat{f}_1$) there exists no regulatory policy that lets the firm report and the optimal policy that lets the firm not report is $\hat{p}^*_{nr} = \frac{b}{\mu}$;*

2. *if $\hat{f}_1$ is small ($\frac{b}{\mu}\hat{f}_2 \geq \hat{f}_1$) the optimal inspection frequency is $\hat{p}^*_r = \frac{\hat{f}_1}{\hat{f}_2}$ to induce reporting and is $\hat{p}^*_{nr} = \frac{\hat{f}_1}{\hat{f}_2} - \epsilon$ with ϵ arbitrarily close to zero to induce no report.*

15.3 Reporting versus no reporting in the presence of the prosecutor

Having described how to optimally implement reporting or not reporting we now determine which of the two outcomes the regulator prefers. As the previous analysis shows two situations are possible. If $\hat{f}_1$ is large the regulator cannot make $\hat{p}\hat{f}_2$ high enough to deter the firm from not reporting. Thus, the regulator then has to choose the policy that leads to no reports. If instead $\hat{f}_1$ is small the regulator sets $\hat{p}^*_r = \frac{\hat{f}_1}{\hat{f}_2}$ to induce a report and $\hat{p}^*_{nr} = \frac{\hat{f}_1}{\hat{f}_2} - \epsilon$ else. The respective levels of care $\hat{x}_r^*$ and $\hat{x}_{nr}^*$ are given by

$$1 + \sigma_x\left(\hat{x}_r^*\right)\hat{f}_1 = 0$$

and

$$\begin{aligned} 1 + \sigma_x\left(\hat{x}_{nr}^*\right)\hat{p}_{nr}^*\hat{f}_2 &= 0 \\ 1 + \sigma_x\left(\hat{x}_{nr}^*\right)\left[\frac{\hat{f}_1}{\hat{f}_2} - \epsilon\right]\hat{f}_2 &= 0 \end{aligned}$$

so that because $\epsilon \to 0$ we get $\hat{x}_{nr}^* \to \hat{x}_r^*$. The difference in the regulator's objective $\Delta\left(\hat{x}_r^*, \hat{x}_{nr}^*\right)$ is then

$$\begin{aligned} \Delta\left(\hat{x}_r^*, \hat{x}_{nr}^*\right) &= \sigma\left(\hat{x}_r^*\right)\delta d - \sigma\left(\hat{x}_{nr}^*\right)\left[1 - (1-\delta)\hat{p}_{nr}^*\right]d \\ &\overset{\hat{x}_{nr}^* \to \hat{x}_r^*}{\to} \sigma\left(\hat{x}_r^*\right)\left\{\delta - 1 + (1-\delta)\frac{\hat{f}_1}{\hat{f}_2}\right\}d \\ &= \sigma\left(\hat{x}_r^*\right)(1-\delta)\left(\frac{\hat{f}_1}{\hat{f}_2} - 1\right)d < 0. \end{aligned}$$

If the prosecutor is involved in the enforcement process the regulator prefers to induce reporting, if feasible. The reason is the same as before. This gives us

Proposition III.5 *In the presence of the prosecutor then*

1. *if $\hat{f}_1$ is large the regulator is bound to a policy inducing no reports and*
2. *if $\hat{f}_1$ is small prefers the policy that optimally induces the firm to report.*

16 Desirability of criminalization

In the previous sections we showed that whenever feasible a regulator concerned about environmental quality prefers policies that let the firm report an accident. In this section we compare the outcomes for the regulator if the prosecutor is present and not present respectively. If regulation is solely delegated to the regulator the outcome depends on the relative size of the feasible maximum (expected) regulatory fines, i.e. on whether $\frac{b}{\mu}\bar{f}_2 \geq \bar{f}_1$. In the presence of the prosecutor the outcome depends on the relative size of the (expected) criminal sanctions, i.e. on whether $\frac{b}{\mu}\hat{f}_2 \geq \hat{f}_1$. Therefore, four situations can occur. The results are summarized in

Proposition III.6 *Criminalizing environmental offences with a prosecutor operating under the legality principle can lead to lower environmental quality compared to regulation without the prosecutor*

1. *if $\hat{f}_1$ is small and the prosecutor lowers deterrence and*
2. *if $\hat{f}_1$ is large and (i) either the prosecutor lowers deterrence or (ii) the effect of higher deterrence does not offset the loss of certain recovery.*

In the following, we consider all cases in more detail.

Small $\hat{f}_1$, large $\bar{f}_1$ If $\hat{f}_1$ is small the regulator can induce reporting in the presence of the prosecutor. If $\bar{f}_1$ is large the policy in the absence of the prosecutor is $\left\{p_r^*, f_{1,r}^*, f_{2,r}^*\right\} = \left\{\frac{b}{\mu}, \frac{b}{\mu}\bar{f}_2, \bar{f}_2\right\}$. The levels of care are given by

$$1 + \sigma_x\left(x_r^*\right)\frac{b}{\mu}\bar{f}_2 = 0$$

and

$$1+\sigma_x\left(\hat{x}_r^*\right)\hat{f}_1=0.$$

Thus, $x_r^* < \hat{x}_r^*$ if $\frac{b}{\mu}\bar{f}_2 < \hat{f}_1$ and vice versa. We get

$$\Delta\left(x_r^*,\hat{x}_r^*\right)=\sigma\left(x_r^*\right)\delta d-\sigma\left(\hat{x}_r^*\right)\delta d=\left\{\sigma\left(x_r^*\right)-\sigma\left(\hat{x}_r^*\right)\right\}\delta d.$$

This is negative if $\hat{f}_1 < \frac{b}{\mu}\bar{f}_2$ and thus in this case adding the prosecutor leads to an increase in damages if he lowers deterrence.

Small $\hat{f}_1$, small $\bar{f}_1$ If instead $\bar{f}_1$ is small the regulator sets $\left\{p_r^*, f_{1,r}^*, f_{2,r}^*\right\} = \left\{\frac{b}{\mu}, \bar{f}_1, \bar{f}_2\right\}$ in the absence of the prosecutor. Then

$$1+\sigma_x\left(x_r^*\right)\bar{f}_1=0$$

and

$$1+\sigma_x\left(\hat{x}_r^*\right)\hat{f}_1=0$$

so that $x_r^* < \hat{x}_r^*$ if $\bar{f}_1 < \hat{f}_1$. The relative advantage of adding the prosecutor is then

$$\Delta\left(x_r^*,\hat{x}_r^*\right)=\sigma\left(x_r^*\right)\delta d-\sigma\left(\hat{x}_r^*\right)\delta d=\left\{\sigma\left(x_r^*\right)-\sigma\left(\hat{x}_r^*\right)\right\}\delta d$$

and $\Delta\left(x_r^*,\hat{x}_r^*\right) < 0$ if $\hat{f}_1 < \bar{f}_1$.

Large $\hat{f}_1$, large $\bar{f}_1$ Now, if $\hat{f}_1$ is large, there exists no feasible inspection frequency $\hat{p}$ that ensures that the firm reports an accident in the presence of the prosecutor. The regulator sets $\hat{p}_{nr}^* = \frac{b}{\mu}$ to get a level of care that is as large as possible. A large $\bar{f}_1$ means that in the absence of the prosecutor the policy is $\left\{p_r^*, f_{1,r}^*, f_{2,r}^*\right\} = \left\{\frac{b}{\mu}, \frac{b}{\mu}\bar{f}_2, \bar{f}_2\right\}$. The respective levels of care are defined by

$$1+\sigma_x\left(x_r^*\right)\frac{b}{\mu}\bar{f}_2=0$$

and

$$1+\sigma_x\left(\hat{x}_{nr}^*\right)\frac{b}{\mu}\hat{f}_2=0$$

so that $x_r^* < \hat{x}_{nr}^*$ if $\bar{f}_2 < \hat{f}_2$ and vice versa. The difference in the regulator's objective is

$$\begin{aligned}
\Delta\left(x_r^*, \hat{x}_{nr}^*\right) &= \sigma\left(x_r^*\right)\delta d - \sigma\left(\hat{x}_{nr}^*\right)\left[1-(1-\delta)\frac{b}{\mu}\right]d \\
&= \left\{\sigma\left(x_r^*\right)\delta - \sigma\left(\hat{x}_{nr}^*\right)\left[1-(1-\delta)\frac{b}{\mu}\right]\right\}d
\end{aligned}$$

If, first, the prosecutor lowers deterrence, i.e. $\bar{f}_2 \geq \hat{f}_2$, and so $x_r^* > \hat{x}_{nr}^*$ this expression is negative for two reasons. On the one hand, the firm exerts less care in the presence of the prosecutor. On the other hand, the fine structure brought along with the prosecutor renders a policy inducing reporting impossible thus removing the possiblity of certain recovery. Formally, this is because

$$\begin{aligned}
\Delta\left(x_r^*, \hat{x}_{nr}^*\right) &= \left\{\sigma\left(x_r^*\right)\delta - \sigma\left(\hat{x}_{nr}^*\right) + \sigma\left(\hat{x}_{nr}^*\right)\frac{b}{\mu} - \sigma\left(\hat{x}_{nr}^*\right)\frac{b}{\mu}\delta\right\}d \\
&= \left\{\left(\sigma\left(x_r^*\right) - \sigma\left(\hat{x}_{nr}^*\right)\frac{b}{\mu}\right)\delta - \left(1-\frac{b}{\mu}\right)\sigma\left(\hat{x}_{nr}^*\right)\right\}d \\
&\overset{\sigma(x_r^*)<\sigma(\hat{x}_{nr}^*)}{<} \left\{\left(1-\frac{b}{\mu}\right)\delta\sigma\left(\hat{x}_{nr}^*\right) - \left(1-\frac{b}{\mu}\right)\sigma\left(\hat{x}_{nr}^*\right)\right\}d \\
&= (\delta-1)\left(1-\frac{b}{\mu}\right)\sigma\left(\hat{x}_{nr}^*\right)d < 0
\end{aligned}$$

If, second, the prosecutor increases deterrence, i.e. $\bar{f}_2 < \hat{f}_2$, and so $x_r^* < \hat{x}_{nr}^*$, $\Delta\left(x_r^*, \hat{x}_{nr}^*\right)$ can either be negative or positive as then two countervailing effects are at work. On the one hand, adding the prosecutor is accompanied by more deterrence leading to a higher level of care. On the other hand, again, a policy inducing reporting is impossible which means that adding the prosecutor partially offsets the benefits from certain recovery. Which effect prevails depends on the precise parameters. Criminalizing environmental offences then leads to more damages if:

$$\left(\sigma\left(x_r^*\right) - \sigma\left(\hat{x}_{nr}^*\right)\frac{b}{\mu}\right)\delta < \left(1-\frac{b}{\mu}\right)\sigma\left(\hat{x}_{nr}^*\right)$$

Large $\hat{f}_1$, small $\bar{f}_1$ Finally, if instead $\bar{f}_1$ is small we get

$$1 + \sigma_x(x_r^*)\,\bar{f}_1 = 0$$

and

$$1 + \sigma_x(\hat{x}_{nr}^*)\,\frac{b}{\mu}\hat{f}_2 = 0$$

and so $x_r^* < \hat{x}_{nr}^*$ if $\bar{f}_1 < \frac{b}{\mu}\hat{f}_2$. Then,

$$\begin{aligned}
\Delta(x_r^*, \hat{x}_{nr}^*) &= \sigma(x_r^*)\,\delta d - \sigma(\hat{x}_{nr}^*)\left[1 - (1-\delta)\frac{b}{\mu}\right]d \\
&= \left\{\sigma(x_r^*)\,\delta - \sigma(\hat{x}_{nr}^*)\left[1 - (1-\delta)\frac{b}{\mu}\right]\right\}d.
\end{aligned}$$

The conclusion here is analog to the case of $\hat{f}_1$ and $\bar{f}_1$ both being large.

17 Conclusion to part III

The paper's main finding as stated in proposition III.6 is that criminalizing environmental offences can have adverse effects on environmental quality. This can result even if criminal sanctions are harsher than administrative fines. The reason is that imposing criminal sanctions is accompanied with an altered institutional setting that in many circumstances does not align public procedures and private incentives. In many countries criminal prosecution follows restrictive rules. One such rule states that all perpetrators have to be prosecuted (legality principle). Additionally, the sanctions actually imposed do not necessarily yield proper incentives for violators to 'voluntary' report misconducts. Analyzing jointly both restrictions reveals that establishing an unbalanced environmental criminal code can be counterproductive.

The mechanism responsible for the paper's reasoning already points to solutions to overcome the shortcomings that might come along with the criminalization of environmental offences.[1] Three customizations present themselves. The first - and most realistic - is to endow the regulator with discretionary power to determine the frequency of passing information about violations to the prosecutor. On the one hand, this retains the threat of criminal sanctioning[2] and, on the other hand, it allows the regulator to set a policy that supports self-reporting. The second is to prescribe sanctions that take into account the incentives for self-reporting. A third solution sets the regulator's budget sufficiently high. In case the criminal sanction for accidents reported is large this can ensure more severe sanctions for not reporting.

[1] See also Jost (1997b) who analyzes different procedural rules with a special focus on the possibility of appeals but does not consider self-reporting.

[2] This threat of criminal prosecution can be important especially in a dynamic setting (see for example Harrington 1988).

Taken together we showed that the well-intentioned criminalization of environmental offences can lead to unintentioned and undesirable effects. The paper calls for policy makers to carefully assess the consequences when implementing criminal proceedings in the context of environmental misconducts and to align public prosecutions with the incentives of those agents adressed by the law.

Part IV

Final Conclusions

This thesis extends the economic literature on monitoring and enforcement by providing detailed analyses of different important aspects of three-party settings. Parts I and II consider the widely overlooked role of private monitoring. Part III focuses on some consequences of a regulator and the prosecutor jointly acting in the monitoring and enforcement process. Thereby, the analyses derive some important results.

18 Summary of results

The game-theoretic model in part I focuses on the interaction between regulatory rule making and citizen reporting. It shows that simply allowing for citizen reports does not necessarily improve regulatory outcomes. In a situation with heterogeneous agents, i.e. for some agents engaging in a socially harmful activity the private benefits exceed the harm caused whereas for others benefits are smaller, information provision by citizens has implications for the stage of rule design. If citizens are willing to incur the costs of reporting only if their action contributes to enforcement actions a prerequisite for substitution of costly public monitoring is (a sufficiently high chance) that the citizen's observation indeed constitutes a violation. Rules tailored to private benefits yield an outcome where only agents with high benefits commit an act. This, in turn, implies that citizens do not report and so their informational advantage cannot be harnessed to save monitoring costs. The reason is that - without an explicit indicator - citizens cannot assess what type of agent they face. The resulting informational imperfection can be overcome, however, by a regulator imposing a uniform rule. Besides a uniform allowance (naturally accompanied with no monitoring and enforcement), the regulator can choose a uniform ban with the benefit of saving monitoring costs due to the deterrence unfold by citizen reporting. Nevertheless, for such a policy to be effective the regulator has to incur one of two previously not considered types of cost. The monitoring and enforcement policy will either result in no agent or only in high type agents committing the act. The former outcome leads to a loss in high type net benefits whereas the latter implies investigation costs on *high* types. The analysis in part I characterizes the circumstances where a uniform ban leads to benefits compared to tailored rules. Moreover, it is shown that apparently promising modifications in (i) the regulator's strategy set of monitoring and enforcement variables and (ii) the citizens' motivation for reporting narrow the set of equilibrium outcomes. In the former case all equilibria where citizen reporting can improve the outcome disappear. Under the latter the two equilibria that feature reporting and thus investigations matter disappear as well. Whether the regulator can realize the outcome where he forfeits high type net benefits depends on the citizen's equilibrium strategy.

Contrary to part I the model in part II takes imperfections in citizen monitoring into account. It shows that increasing citizens' capability to detect violations is not unambiguously welfare enhancing. In a 'no inspection equilibrium' a better technology yields the intuitive outcome, i.e. lower harm. However, in the 'full sampling equilibrium' where a public regulator, a polluter and affected citizens jointly determine the outcome increasing the citizens' monitoring technology's accuracy has two effects. On the one hand, there is a greater chance that an actual pollution event is detected and subsequently investigated, thus leading to a crowding-in of public enforcement. On the other hand, this allows the regulator to substitute public monitoring by the increased deterrence of private monitoring. Jointly, these effects can lead to more harm. The reason is that the regulator only inspects if the chance of finding pollution is sufficiently high. Now, keeping the pollution frequency constant, a better sampling technology lowers exactly that chance. In equilibrium this has to be offset by a higher pollution frequency. Whether the resulting savings in public monitoring costs exceed the increase in harm depends on the parameters. Nevertheless, even if the savings in public monitoring expenditures outweigh the additional harm those who are supposed to adopt the superior sampling technology, i.e. the affected citizens, would face a decrease in their welfare.

The model in part III does not consider private monitoring but modifications in public monitoring and enforcement. It analyzes some of the consequences of separating public monitoring and enforcement. On the one hand, a regulator still monitors a firm's environmental performance. On the other hand, a public prosecutor takes over enforcement. Focusing on the prosecutor's legal framework, in particular on the legality principle and constrained sanctioning discretion, the model shows that criminalizing environmental violations can lead to less environmental quality. Although in many - but not all - situations the criminal law provides harsher sanctions for environmental offences than the administrative law imposing criminal penalties can worsen the outcome. This result stems from the fact that it is beneficial that firms report violations as this allows regulatory authorities to prevent environmental damages by ordering recovery actions. The constrained sanctioning discretion inherent in the criminal system, however, can dilute a firm's incentive to self-report. The analysis shows that it is beneficial to bring on the criminal law on environmental violators (i) if it does not prevent self-reporting and increases deterrence or (ii) if the benefits from higher deterrence - resulting in less damages due to more care excerted by firms - exceed the increase in persistent damages due to unreported, undetected and therefore unrecovered violations.

Taken together, this thesis provides some important insights into the economic mechanisms of trilateral monitoring and enforcement situations. It acknowledges the potential for improving on the effectiveness and efficiency of monitoring and enforcement. At the same time the findings illustrate that opening the public monitoring and enforcement process for third parties can have unexpected and undesirable consequences. Thereby it shows that when evaluating third-party participation it is important (i) to take a close look at the incentives of all actors, (ii) to recognize all costs involved, and (iii) to explicitly consider the legal framework all parties are acting in.

19 Areas for future research

This thesis provides the potential for further fruitful analyses *within the fields* of, first, private monitoring and, second, separated public monitoring and enforcement. From a *broader perspective* the present thesis is an important step towards a comprehensive understanding of joint public and private monitoring and enforcement. Nevertheless, for such a broad understanding a number of important questions remain unanswered.

19.1 Private Monitoring, Separated Public Monitoring and Enforcement

Within the field of private monitoring especially part II provides scope for interesting *theoretical* modifications. One limiting assumption is that the technological progress of the applied monitoring device does only enhance the monitoring accuracy but does not alter sampling costs. The analysis reveals, however, that sampling costs enter the equilibrium strategies and the outcomes in an essential way. Therefore, it would be interesting to see how robust the findings are with respect to a technological progress that contemporaneously affects the error probability and sampling costs. A closely related modification would enlarge the citizen's strategy set. In some circumstances it appears reasonable that the citizen does not only decide whether to sample but also decides how much to spend on sampling. This would yield a situation where the error probability cannot be treated to be exogenous but where it is endogenously determined by the citizen. Finally, part II does not compare the two outcomes that can emerge under a high and a low error probability respectively. It only considers changes in the neighborhood of the established technology. A more detailed analysis will show whether it is beneficial to invest sufficient resources in order to turn a high error probability into a low one. *Empirically* it can be tested whether (better) private monitoring has indeed an impact on public monitoring and public enforcement behavior. As citizen monitoring initiatives are widespread such an analysis should be able to exploit variations in time, space and legal or other institutional frameworks. Finally, *experiments* will reveal individuals' willingness to pay to acquire more or better information about others' misconducts.

With respect to the separation of public monitoring and enforcement part III focusses on the effects of criminalization on environmental quality and a broadening to a welfare perspective is necessary to theoretically assess whether increasing the scope of application of the criminal law is indeed beneficial. Empirically it would be of interest to see whether criminalizing environmental offences has an impact not only on recorded violations but also on firms' self-reporting behavior.

19.2 Integration of Public and Private Monitoring and Enforcement

According to the distinction between monitoring and enforcement activities on the one hand and public and private parties on the other hand this thesis does not consider the role of private enforcement. Nevertheless, to get a comprehensive understanding of an integrated monitoring and enforcement process it is necessary to analyze the relation between private enforcement and the three other dimensions. *Theoretically*, future research could analyze how the possibility to sue violators affects the incentives for - harmed and not harmed - private parties to carry out monitoring activities. On the one hand, this possibility increases the value of the data generated so that one could expect more sampling. On the other hand, however, using sampling data for private enforcement could additionally lead to a crowding-out of public enforcement, thus diluting the incentives for (harmed) private parties to monitor. Further analysis will reveal the conditions under which the possibility of suits increases or decreases the scope of private monitoring.

From an *empirical* point of view it would be interesting to see whether and, if so, to which extent the data generated by private monitoring are not only used to inform regulators but also serve as evidence in court cases. One conjecture is that (better) private monitoring should lead to more suits as the informational disadvantage of non-governmental organizations compared to industry representatives is narrowed and, therefore, the chance of a successful accusal increases. Moreover, if these data are used in and accepted by courts future research should analyze whether this has an impact on polluters' behavior and ultimately on environmental quality.

Additionally, *experiments* can provide valuable insights. This holds especially for the analysis of monitoring by private parties not harmed by others' behavior. As demonstrated in part I unaffected third parties are willing to incur costs to contribute to the punishment of wrongdoers. With respect to the analysis in part II it would be interesting to see whether unaffected third parties are willing to incur costs to monitor as well. Moreover, experiments can show how monitoring costs affect private monitoring and private enforcement decisions, i.e. whether in practice there is a law of demand in private monitoring and enforcement. Additionally, an experimental set up could exogenously vary 'public' monitoring and enforcement intensities and observe whether individuals monitoring and enforcement behavior reacts to these variations, i.e. whether they indeed recognize potential crowding effects.

Finally, the field of private monitoring and enforcement is linked to the recent trend of regulation through information. Initiatives based on this concept disclose regulatory information to a broader audience, e.g. via the internet. In the context of environmental regulation registers like the U.S. TRI and the European E-PRTR are prominent examples. As this databases include emissions enacting such programs has implications for private monitoring as well as enforcement. At the enforcement stage such data can be valuable inputs for court cases. However, public data provision can, on the one hand, obviously undermine the incentives for private monitoring as this might only duplicate data generation. On the other hand, such data can potentially be complements to the information acquired by private monitoring. Therefore, a theoretical analysis should uncover and analyze the channels how public information disclosure affects private monitoring and enforcement and what the net effects on the effectiveness and efficiency of regulation are. An empirical investigation would ask whether public information disclosure crowds out private monitoring and enforcement. Similar, experiments will show how public information disclosure affects citizen reporting, private information generating activities and private enforcement.

Part V

Appendix to Part I

20 Proof of Proposition I.2

Suppose that the citizen plays $r = 1$ at $H_1^{0,1}$. The regulator then sets $(\{0, 0, 1, w\}_L,$ $\{1, p_H, 0, F_H\})$: Low types comply without inspections being necessary for deterrence because if they commit the act they get reported and have to pay the fine w with probability one, thus getting the negative payoff $\theta_L - w$. High types commit the act although they get reported because they are not investigated and thus do not have to pay the fine. The regulator sets $q_H = 0$ to avoid costly investigations. His payoff is then $V = n_H (\theta_H - h)$ which is the highest possible value for V because only the positive net benefits from high types enter V and neither net damages, inspection costs nor investigation costs occur. However, given this policy and agents' choices a strategy with $\left(r = 1 \text{ if } H_1^{0,1}\right)$ is not sequential rational for the citizen as only agents being allowed commit the act and the payoff from reporting at $H_1^{0,1}$is $-c_R$. Therefore, the citizen's equilibrium play must be $r = 0$ at $H_1^{0,1}$. But the equilibrium is then as in proposition I.1.

21 Proof of Proposition I.3

UP yields V as in (I.3). The payoff for the citizen if $\hat{a} = 0$ and $a_i = 1$, i.e. if the game reaches H_1^0, not only depends on r but also on the agent's type. Therefore, inspections are necessary for FB: Suppose that in equilibrium the citizen plays $r = 1$ at H_1^0. The regulator sets $\{0, p_L = 0, p_H, q_L = 1, q_H = 0, F_L = w, F_H\}$ yielding $V = n_H (\theta_H - h)$ as the highest possible V. Then only high types commit the act. Because $q_H = 0$, no sanctions are imposed. ($r = 1$ if H_1^0) is not sequentially rational and the citizen does not report at H_1^0. To ensure FB the regulator sets $\left\{0, \frac{\theta_L}{w}, \frac{\theta_H}{w}, q_L, q_H, w, w\right\}$. Thus, $V = -n_H \frac{\theta_H}{w} c_{Ins} - n_L \frac{\theta_L}{w} c_{Ins} < 0$ and the lemma does not hold. The argument why the citizen plays $r = 0$ at H_1^0 applies accordingly to $H_1^{0,1}$ and $H_1^{1,0}$ and a ban has to be enforced (partially) through inspections. To induce $a_i = 1$ and $a_{-i} = 0$ the regulator can set TP $\left(\{1, 0, q_i, F_i\}_i, \left\{0, \frac{\theta_{-i}}{w}, q_{-i}, w\right\}_{-i},\right)$ or the uniform policy $\left\{0, p_i = 0, p_{-i} = \frac{\theta_{-i}}{w}, q_i, q_{-i}, F_i, F_{-i} = w\right\}$, both yielding $V = n_i (\theta_i - h) - n_{-i} \frac{\theta_{-i}}{w} c_{Ins}$ where the regulator prefers TP. For $i = L$ this is $-n_H \frac{\theta_H}{w} c_{Ins} - n_L (h - \theta_L)$ which is smaller than that of UP. Finally, comparing the outcome from UP $n_H (\theta_H - h) - n_L (h - \theta_L)$ with that of TP with $\hat{a}_L = 0$ and $\hat{a}_H = 1$, i.e. $n_H (\theta_H - h) - n_L \frac{\theta_L}{w} c_{Ins}$, gives the proposition.

22 Derivation of Figure 4.1

Define the different possible values for $\underline{c}$ as follows: $c_{FB} = n_H (\theta_H - h)$, $c_{UP} = n_L (h - \theta_L)$, $c_{TP} = n_L \frac{\theta_L}{w} c_{Ins}$, $c_{PBD} = n_H \frac{\theta_L}{w} c_{Inv}$, and $c_{PBR} = n_H \frac{c_R}{b} c_{Inv}$. These expressions are set pairwise equal, then solved for $\frac{n_H}{n_L}$ and it is stated how the resulting indifference functions separate the $\left(\theta_L, \frac{n_H}{n_L}\right)$-space. Then, the relations, i.e. the intersections or mutual positions, between these functions are derived and all functions are put into a single graph that captures the respective $\underline{c}$ in each area of the $\left(\theta_L, \frac{n_H}{n_L}\right)$-space.

22.1 The indifference functions are:

$c_{FB} = c_{UP}:$	$n_H(\theta_H - h) = n_L(h - \theta_L) \Leftrightarrow \frac{n_H}{n_L} = \frac{h}{\theta_H - h} - \frac{1}{\theta_H - h}\theta_L$
	$\Rightarrow$ left of '$c_{FB} = c_{UP}$' is $c_{FB} < c_{UP}$ and vice versa
$c_{FB} = c_{TP}:$	$n_H(\theta_H - h) = n_L \frac{\theta_L}{w} c_{Ins} \Leftrightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{(\theta_H - h)w}\theta_L$
	$\Rightarrow$ left of '$c_{FB} = c_{TP}$' is $c_{FB} > c_{TP}$
$c_{FB} = c_{PBD}:$	$n_H(\theta_H - h) = n_H \frac{\theta_L}{w} c_{Inv} \Leftrightarrow \frac{\theta_H - h}{c_{Inv}} w = \theta_L$
	$\Rightarrow$ left of '$c_{FB} = c_{PBD}$' is $c_{FB} > c_{PBD}$
$c_{FB} = c_{PBR}:$	$n_H(\theta_H - h) = n_H \frac{c_R}{b} c_{Inv} \Leftrightarrow \theta_H - h = \frac{c_R}{b} c_{Inv}$
	$\Rightarrow$ independent of θ_L, n_H and n_L
$c_{UP} = c_{TP}:$	$n_L(h - \theta_L) = n_L \frac{\theta_L}{w} c_{Ins} \Leftrightarrow \frac{h}{w + c_{Ins}} w = \theta_L$
	$\Rightarrow$ left of '$c_{UP} = c_{TP}$' is $c_{UP} > c_{TP}$
$c_{UP} = c_{PBD}:$	$n_L(h - \theta_L) = n_H \frac{\theta_L}{w} c_{Inv} \Leftrightarrow \frac{w}{c_{Inv}}\left(-1 + h\frac{1}{\theta_L}\right) = \frac{n_H}{n_L}$
	$\Rightarrow$ left of '$c_{UP} = c_{PBD}$' is $c_{UP} > c_{PBD}$
$c_{UP} = c_{PBR}:$	$n_L(h - \theta_L) = n_H \frac{c_R}{b} c_{Inv} \Leftrightarrow \frac{hb}{c_R c_{Inv}} - \frac{b}{c_R c_{Inv}}\theta_L = \frac{n_H}{n_L}$
	$\Rightarrow$ left of '$c_{UP} = c_{PBR}$' is $c_{UP} > c_{PBR}$
$c_{TP} = c_{PBD}:$	$n_L \frac{\theta_L}{w} c_{Ins} = n_H \frac{\theta_L}{w} c_{Inv} \Leftrightarrow \frac{c_{Ins}}{c_{Inv}} = \frac{n_H}{n_L}$
	$\Rightarrow$ below '$c_{TP} = c_{PBD}$' is $c_{TP} > c_{PBD}$
$c_{TP} = c_{PBR}:$	$n_L \frac{\theta_L}{w} c_{Ins} = n_H \frac{c_R}{b} c_{Inv} \Leftrightarrow \frac{c_{Ins} b}{c_R c_{Inv} w}\theta_L = \frac{n_H}{n_L}$
	$\Rightarrow$ left of '$c_{TP} = c_{PBR}$' is $c_{TP} < c_{PBR}$
$c_{PBD} = c_{PBR}:$	$n_H \frac{\theta_L}{w} c_{Inv} = n_H \frac{c_R}{b} c_{Inv} \Leftrightarrow \theta_L = \frac{c_R}{b} w$
	$\Rightarrow$ left of '$c_{PBD} = c_{PBR}$' is $c_{PBD} < c_{PBR}$

Left (right) of $c_{PBD} = c_{PBR}$ where $c_{PBD} < c_{PBR}$ $(c_{PBR} < c_{PBD})$ the minimum cost criterion $\underline{c}$ cannot be c_{PBD} (c_{PBR}) because only the higher of c_{PBD} and c_{PBR} can be $\underline{c}$.

22.2 Relations between indifference functions

$$c_{FB} = c_{UP} \text{ and } c_{FB} = c_{TP}: \quad \frac{h}{\theta_H - h} - \frac{1}{\theta_H - h}\theta_L = \frac{c_{Ins}}{(\theta_H - h)w}\theta_L \Leftrightarrow$$

$$\theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{hc_{Ins}}{(\theta_H - h)(w + c_{Ins})}$$

$$c_{FB} = c_{UP} \text{ and } c_{FB} = c_{PBD}: \quad \theta_L = \frac{\theta_H - h}{c_{Inv}} w \Rightarrow \frac{n_H}{n_L} = \frac{h}{\theta_H - h} - \frac{w}{c_{Inv}}$$

$$c_{FB} = c_{UP} \text{ and } c_{UP} = c_{TP}: \quad \theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{hc_{Ins}}{(\theta_H - h)(w + c_{Ins})}$$

$c_{FB} = c_{UP}$ and $c_{UP} = c_{PBD}$: $\frac{h}{\theta_H - h} - \frac{1}{\theta_H - h}\theta_L = \frac{w}{c_{Inv}}\left(-1 + h\frac{1}{\theta_L}\right) \Rightarrow$

$\theta_{L,1} = h \Rightarrow \frac{n_H}{n_L} = 0$ and $\theta_{L,2} = \frac{\theta_H - h}{c_{Inv}} w$

$\Rightarrow \frac{n_H}{n_L} = \frac{h}{\theta_H - h} - \frac{w}{c_{Inv}}$

$c_{FB} = c_{UP}$ and $c_{UP} = c_{PBR}$: $\frac{h}{\theta_H - h} - \frac{1}{\theta_H - h}\theta_L = \frac{hb}{c_R c_{Inv}} - \frac{b}{c_R c_{Inv}}\theta_L$

$\Rightarrow \theta_L = h \Rightarrow \frac{n_H}{n_L} = 0;$

$c_{FB} < c_{PBR} \Leftrightarrow \theta_H - h < \frac{c_R}{b} c_{Inv}$

$\Leftrightarrow \frac{1}{\theta_H - h} > \frac{b}{c_R c_{Inv}} \Leftrightarrow \frac{h}{\theta_H - h} > \frac{hb}{c_R c_{Inv}}$

Therefore, if $c_{FB} < c_{PBR}$ then the slope in absolute terms of $c_{FB} = c_{UP}$ is larger than that of $c_{UP} = c_{PBR}$ and the intercept with the $\frac{n_H}{n_L}$-axis of $c_{FB} = c_{UP}$ is larger than that of $c_{UP} = c_{PBR}$ and vice versa.

$c_{FB} = c_{UP}$ and $c_{TP} = c_{PBD}$: $\frac{h}{\theta_H - h} - \frac{1}{\theta_H - h}\theta_L = \frac{c_{Ins}}{c_{Inv}} \Leftrightarrow$

$\theta_L = h - \frac{c_{Ins}}{c_{Inv}}(\theta_H - h) \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{FB} = c_{UP}$ and $c_{TP} = c_{PBR}$: $\frac{h}{\theta_H - h} - \frac{1}{\theta_H - h}\theta_L = \frac{bc_{Ins}}{c_R c_{Inv} w}\theta_L \Leftrightarrow$

$\theta_L = \frac{hc_R c_{Inv} w}{bc_{Ins}(\theta_H - h) + c_R c_{Inv} w} \Rightarrow \frac{n_H}{n_L} = \frac{hbc_{Ins}}{bc_{Ins}(\theta_H - h) + c_R c_{Inv} w}$

$c_{FB} = c_{UP}$ and $c_{PBD} = c_{PBR}$: $\theta_L = \frac{c_R}{b} w \Rightarrow \frac{n_H}{n_L} = \frac{hb - c_R w}{(\theta_H - h)b}$

$c_{FB} = c_{TP}$ and $c_{FB} = c_{PBD}$: $\theta_L = \frac{\theta_H - h}{c_{Inv}} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{FB} = c_{TP}$ and $c_{UP} = c_{TP}$: $\theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{hc_{Ins}}{(\theta_H - h)(w + c_{Ins})}$

$c_{FB} = c_{TP}$ and $c_{UP} = c_{PBD}$: $\frac{c_{Ins}}{(\theta_H - h)w}\theta_L = \frac{w}{c_{Inv}}\left(-1 + h\frac{1}{\theta_L}\right) \Rightarrow$

solution is not necessarily a rational expression.

$c_{FB} = c_{TP}$ and $c_{UP} = c_{PBR}$: $\frac{c_{Ins}}{(\theta_H - h)w}\theta_L = \frac{hb}{c_R c_{Inv}} - \frac{b}{c_R c_{Inv}}\theta_L \Leftrightarrow$

$\theta_L = \frac{hb(\theta_H - h)w}{c_{Ins} c_R c_{Inv} + b(\theta_H - h)w} \Rightarrow \frac{n_H}{n_L} = \frac{hbc_{Ins}}{c_{Ins} c_R c_{Inv} + b(\theta_H - h)w}$

$c_{FB} = c_{TP}$ and $c_{TP} = c_{PBD}$: $\frac{c_{Ins}}{(\theta_H - h)w}\theta_L = \frac{c_{Ins}}{c_{Inv}} \Leftrightarrow$

$\theta_L = \frac{(\theta_H - h)}{c_{Inv}} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{FB} = c_{TP}$ and $c_{TP} = c_{PBR}$: $\frac{c_{Ins}}{(\theta_H - h)w}\theta_L = \frac{c_{Ins} b}{c_R c_{Inv} w}\theta_L \Rightarrow \theta_L = 0 \Rightarrow \frac{n_H}{n_L} = 0;$

$c_{FB} < c_{PBR} \Leftrightarrow \theta_H - h < \frac{c_R}{b} c_{Inv}$

$\Leftrightarrow \frac{1}{\theta_H - h} > \frac{b}{c_R c_{Inv}} \Leftrightarrow \frac{c_{Ins}}{(\theta_H - h)w} > \frac{bc_{Ins}}{c_R c_{Inv} w}$

Therefore, if $c_{FB} < c_{PBR}$ then the slope of $c_{FB} = c_{TP}$ is greater than that of $c_{TP} = c_{PBR}$ and vice versa.

$c_{FB} = c_{TP}$ and $c_{PBD} = c_{PBR}$: $\theta_L = \frac{c_R}{b} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins} c_R}{(\theta_H - h)b}$

$c_{FB} = c_{PBD}$ and $c_{UP} = c_{TP}$: no intersection because both vertical lines.

$c_{FB} = c_{PBD}$ and $c_{UP} = c_{PBD}$: $\quad \theta_L = \frac{\theta_h - h}{c_{Inv}} w \Rightarrow \frac{n_H}{n_L} = \frac{h}{\theta_H - h} - \frac{w}{c_{Inv}}$

$c_{FB} = c_{PBD}$ and $c_{UP} = c_{PBR}$: $\quad \theta_L = \frac{\theta_H - h}{c_{Inv}} w \Rightarrow \frac{n_H}{n_L} = \frac{hbc_{Inv} - b(\theta_H - h)w}{c_R c_{Inv}^2}$

$c_{FB} = c_{PBD}$ and $c_{TP} = c_{PBD}$: $\quad \theta_L = \frac{\theta_H - h}{c_{Inv}} w$ and $\frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{FB} = c_{PBD}$ and $c_{TP} = c_{PBR}$: $\quad \theta_L = \frac{\theta_H - h}{c_{Inv}} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins} b(\theta_H - h)}{c_R c_{Inv}^2}$

$c_{FB} = c_{PBD}$ and $c_{PBD} = c_{PBR}$: $\quad$ no intersection because both vertical lines. However, if $c_{FB} < c_{PBR}$ then $n_H \left(\theta_H - h\right) < n_H \frac{c_R}{b} c_{Inv}$ and thus $\frac{\theta_H - h}{c_{Inv}} w < \frac{c_R}{b} w$. Therefore, if $c_{FB} < c_{PBR}$ then $c_{FB} = c_{PBD}$ is left of $c_{PBD} = c_{PBR}$ and vice versa.

$c_{UP} = c_{TP}$ and $c_{UP} = c_{PBD}$: $\quad \theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{UP} = c_{TP}$ and $c_{UP} = c_{PBR}$: $\quad \theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{hbc_{Ins}}{c_R c_{Inv}(w + c_{Ins})}$

$c_{UP} = c_{TP}$ and $c_{TP} = c_{PBD}$: $\quad \theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{UP} = c_{TP}$ and $c_{TP} = c_{PBR}$: $\quad \theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{hbc_{Ins}}{c_R c_{Inv}(w + c_{Ins})}$

$c_{UP} = c_{TP}$ and $c_{PBD} = c_{PBR}$: $\quad$ no intersection because both vertical lines.

$c_{UP} = c_{PBD}$ and $c_{UP} = c_{PBR}$: $\quad \frac{w}{c_{Inv}} \left(-1 + \frac{h}{\theta_L}\right) = \frac{hb}{c_R c_{Inv}} - \frac{b}{c_R c_{Inv}} \theta_L \Rightarrow$
$\theta_{L,1} = h \Rightarrow \frac{n_H}{n_L} = 0$ and $\theta_{L,2} = \frac{c_R}{b} w$
$\Rightarrow \frac{n_H}{n_L} = \frac{hb}{c_R c_{Inv}} - \frac{w}{c_{Inv}}$

$c_{UP} = c_{PBD}$ and $c_{TP} = c_{PBD}$: $\quad \frac{w}{c_{Inv}} \left(-1 + h \frac{1}{\theta_L}\right) = \frac{c_{Ins}}{c_{Inv}} \Leftrightarrow$
$\theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{UP} = c_{PBD}$ and $c_{TP} = c_{PBR}$: $\quad \frac{w}{c_{Inv}} \left(-1 + \frac{h}{\theta_L}\right) = \frac{c_{Ins} b}{c_R c_{Inv} w} \theta_L \Rightarrow$
solution not necessarily rational

$c_{UP} = c_{PBD}$ and $c_{PBD} = c_{PBR}$: $\quad \theta_L = \frac{c_R}{b} w \Rightarrow \frac{n_H}{n_L} = \frac{hb}{c_R c_{Inv}} - \frac{w}{c_{Inv}}$

$c_{UP} = c_{PBR}$ and $c_{TP} = c_{PBD}$: $\quad \frac{hb}{c_R c_{Inv}} - \frac{b}{c_R c_{Inv}} \theta_L = \frac{c_{Ins}}{c_{Inv}} \Leftrightarrow$
$\theta_L = h - \frac{c_R c_{Ins}}{b} \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{UP} = c_{PBR}$ and $c_{TP} = c_{PBR}$: $\quad \frac{hb}{c_R c_{Inv}} - \frac{b}{c_R c_{Inv}} \theta_L = \frac{bc_{Ins}}{c_R c_{Inv} w} \theta_L \Leftrightarrow$
$\theta_L = \frac{h}{w + c_{Ins}} w \Rightarrow \frac{n_H}{n_L} = \frac{hbc_{Ins}}{c_R c_{Inv}(w + c_{Ins})}$

$c_{UP} = c_{PBR}$ and $c_{PBD} = c_{PBR}$: $\quad \theta_L = \frac{c_R}{b} w \Rightarrow \frac{n_H}{n_L} = \frac{hb}{c_R c_{Inv}} - \frac{w}{c_{Inv}}$

$c_{TP} = c_{PBD}$ and $c_{TP} = c_{PBR}$: $\quad \frac{c_{Ins} b}{c_R c_{Inv} w} \theta_L = \frac{c_{Ins}}{c_{Inv}} \Leftrightarrow$
$\theta_L = \frac{c_R}{b} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{TP} = c_{PBD}$ and $c_{PBD} = c_{PBR}$: $\quad \theta_L = \frac{c_R}{b} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

$c_{TP} = c_{PBR}$ and $c_{PBD} = c_{PBR}$: $\quad \theta_L = \frac{c_R}{b} w \Rightarrow \frac{n_H}{n_L} = \frac{c_{Ins}}{c_{Inv}}$

At seven points more than two functions intersect: (i) $c_{FB} = c_{UP}$, $c_{FB} = c_{TP}$ and $c_{UP} = c_{TP}$ at $\left(\frac{hw}{w+c_{Ins}}, \frac{hc_{Ins}}{(\theta_H - h)(w+c_{Ins})}\right)$, (ii) $c_{FB} = c_{UP}$, $c_{FB} = c_{PBD}$ and $c_{UP} = c_{PBD}$ at $\left(\frac{\theta_H - h}{c_{Inv}} w, \frac{h}{\theta_H - h} - \frac{w}{c_{Inv}}\right)$, (iii) $c_{FB} = c_{TP}$, $c_{FB} = c_{PBD}$ and $c_{TP} = c_{PBD}$ at $\left(\frac{\theta_H - h}{c_{Inv}} w, \frac{c_{Ins}}{c_{Inv}}\right)$, (iv) $c_{UP} = c_{TP}$, $c_{UP} = c_{PBD}$ and $c_{TP} = c_{PBD}$ at $\left(\frac{hw}{w+c_{Ins}}, \frac{c_{Ins}}{c_{Inv}}\right)$, (v) $c_{UP} = c_{TP}$, $c_{UP} = c_{PBR}$ and $c_{TP} = c_{PBR}$ at $\left(\frac{hw}{w+c_{Ins}}, \frac{hbc_{Ins}}{c_R c_{Inv}(w+c_{Ins})}\right)$, (vi) $c_{UP} = c_{PBD}$, $c_{UP} = c_{PBR}$ and $c_{PBD} = c_{PBR}$ at $\left(\frac{c_R}{b} w, \frac{hb}{c_R c_{Inv}} - \frac{w}{c_{Inv}}\right)$, and (vii) $c_{TP} = c_{PBD}$, $c_{TP} = c_{PBR}$ and $c_{PBD} = c_{PBR}$ at $\left(\frac{c_R}{b} w, \frac{c_{Ins}}{c_{Inv}}\right)$.

Because the relation between c_{FB} and c_{PBR} determines the relation between the two vertical indifference functions $c_{FB} = c_{PBD}$ and $c_{PBD} = c_{PBR}$ and because with $c_{UP} = c_{TP}$ there are three vertical indifference functions six situations are possible. Figures 22.1, 22.2, and 22.3 put all indifference functions into a single graph for the three cases shown in figure 4.1 where $c_{FB} > c_{PBR}$ which implies that $c_{FB} = c_{PBD}$ is right of $c_{PBD} = c_{PBR}$. Additionally figures 22.1, 22.2, and 22.3 show in which area which equilibrium prevails.

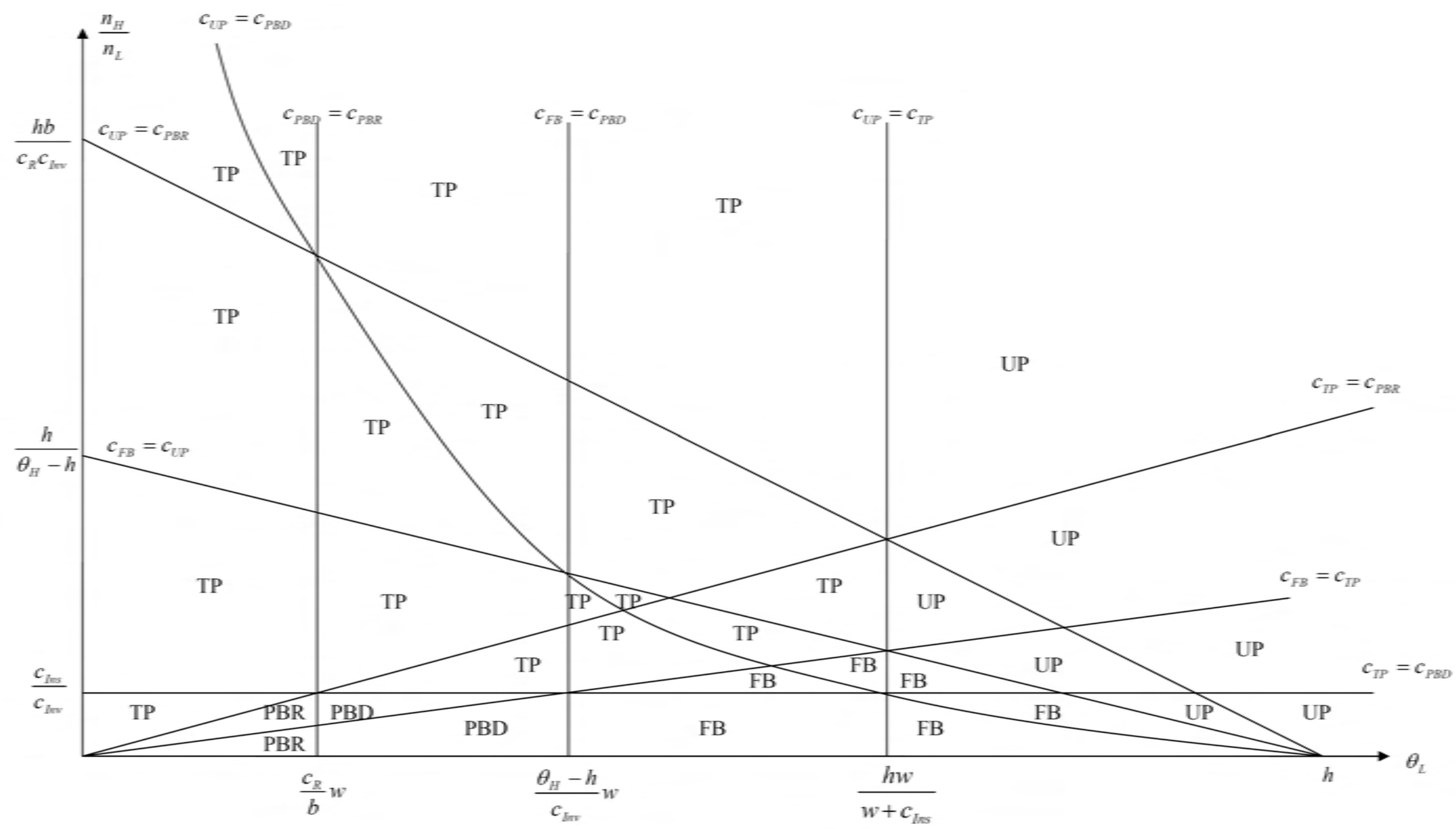

Figure 22.1: 1. case: $\frac{c_R}{b} w < \frac{\theta_H - h}{c_{Inv}} w < \frac{hw}{w + c_{Ins}}$.

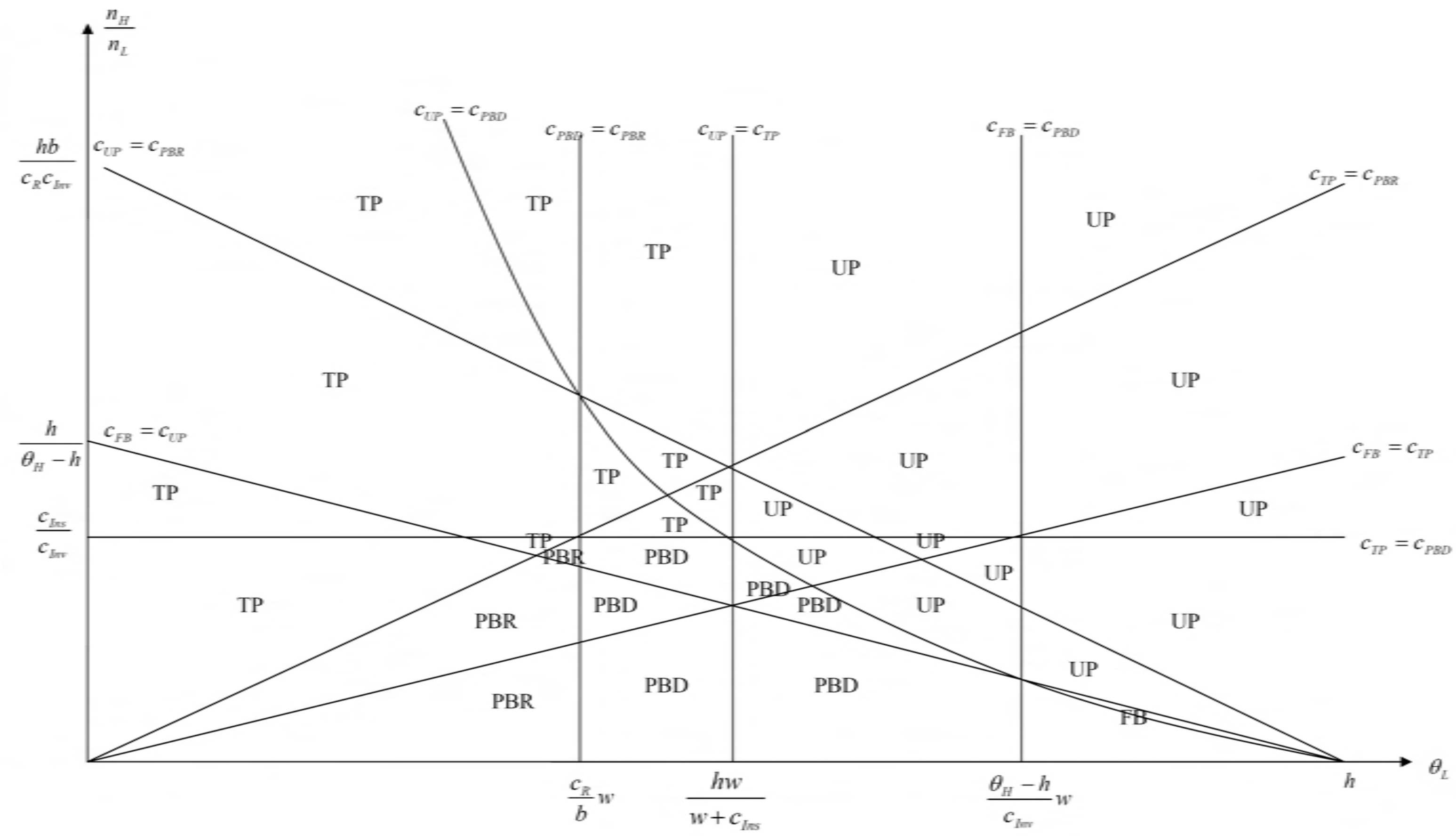

Figure 22.2: 2. case: $\frac{c_R}{b} w < \frac{hw}{w+c_{Ins}} < \frac{\theta_H - h}{c_{Inv}} w$.

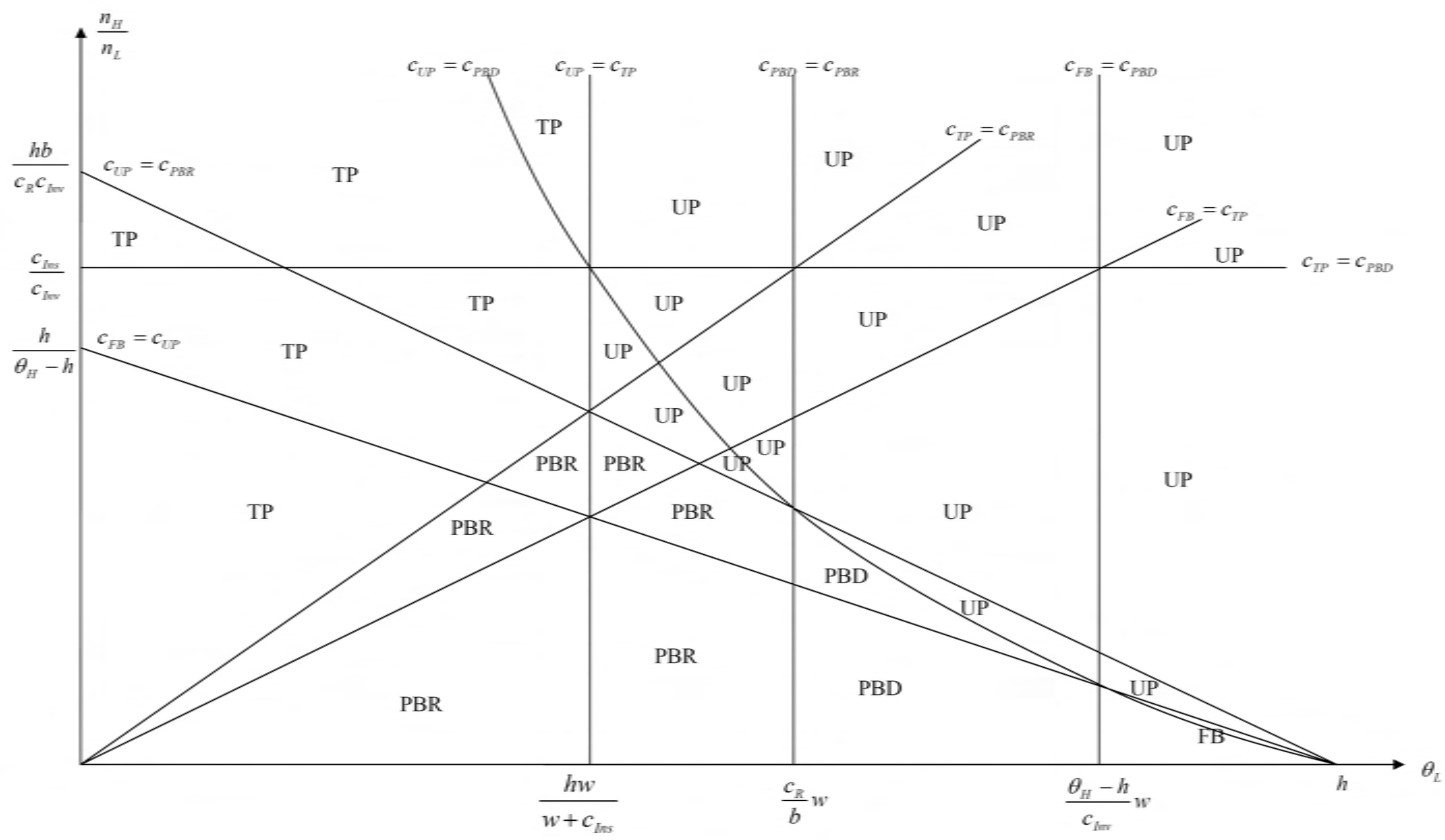

Figure 22.3: 3. case: $\frac{hw}{w+c_{Ins}} < \frac{c_R}{b}w < \frac{\theta_H - h}{c_{Inv}}w$.

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